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Monitoring project impact on biomass increase in the context of the Great Green Wall for the Sahara and Sahel Initiative in Senegal

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Abstract

Land degradation and desertification represent a major threat to the population and ecosystems of (semi)-arid regions like the Sahel and the Sahara. In 2007, the African Union launched a pan-African programme, the Great Green Wall for the Sahara and the Sahel Initiative (GGWSSI) to reverse land degradation and desertification in the region, improve food security and support local people to adapt to climate change. Within the GGWSSI different kinds of projects have been implemented. In order to quickly evaluate the effectiveness of (a large number of) restoration and sustainable rangeland/agriculture projects, a methodology to remotely assess the biophysical impacts of diverse interventions is desirable.

Within the Administrative Arrangement *Technical and scientific Support to agriculture and Food and Nutrition Security* we aim to develop a multi-scale remote sensing (RS) based approach to monitor the biophysical impact of sustainable agriculture and rangeland projects. Specifically, we propose to utilize a biophysical indicator obtained via satellite imagery and compare the difference between project sites and corresponding reference sites before and after the intervention. Besides this specific comparison between project and reference sites, the general state and development of vegetation and other parameters (like precipitation) on a larger scale are important information for project planning in general and the project impact assessment. This report focuses on this general analysis of vegetation and precipitation trends in north Senegal and provides some first basic approaches for RS-based impact assessment on biomass increase of selected GGWSSI projects. An upcoming paper will concentrate on a more advanced approach of impact assessment.

Time series of satellite-derived precipitation estimates (P, the main driver of vegetation growth in the area) and Normalized Difference Vegetation Index (NDVI, indicating vegetation amount and health status) data were utilised to characterize general precipitation and vegetation characteristics in the region and to compute long- (for P) and short-term linear trends (for P and NDVI). This is important to distinguish between general climatic trends in the region and vegetation trends due to project intervention. The results indicate a significant long-term increase in annual precipitation sums over the period 1981–2014 in the study area, while there is no significant precipitation trend in the more recent (and shorter) time period (2001–2014). The NDVI-based analysis of vegetation revealed some local positive and negative trends. As there is no significant precipitation trend over this time, we assume that other/additional factors than precipitation changes need to be considered as drivers for the vegetation trends. For an in-depth analysis of local vegetation changes (also with respect to land degradation) future studies should also include other sources of information (e.g. field studies, interviews of local people).

The basic assessment of possible biophysical impacts of selected restoration projects was done via visual inspection of very high resolution images before and after the intervention and by computing differences of maxNDVI between project sites and reference sites. For some projects, slight positive changes after the intervention could be observed, indicating an increase of biomass. Other projects did not show any visible positive effect of the interventions. Further research is currently in progress to develop a more automatized and statistically sound method for this type of comparison. Should this advanced approach confirm the failure of some projects, further studies should be undertaken to understand the reasons for the failure to guide future interventions and project planning/monitoring.

1. Introduction

1.1 Background

Desertification threatens the livelihood of people in the Sahel and the Sahara, which represent one of the world's poorest population. The United Nations Convention to Combat Desertification defines desertification as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climate variation and human activities" (UNCCD 1994). Land degradation itself represents the reduction or loss of biological or economic productivity in dryland ecosystems (Millennium Ecosystem Assessment 2005). Besides physically affecting ecosystems, land degradation causes various socio-economic problems like food insecurity, water shortage, poverty, health problems, and conflicts (Mbow et al. 2015). However, the assessment and quantification of land degradation is challenging due to the complex nature of the phenomena and various data constraints. Due to the scarcity of ground observations in African drylands, remote sensing data has been widely applied to study degradation in this region. Despite four decades of Earth Observation (EO) application, there is no consensus on the direction and magnitude of land degradation in the Sahel (Mbow et al. 2015). While many studies indicate an overall greening of the Sahel, other studies show no trend or even a browning (hence degradation). According to the review of Mbow et al. (2015) these inconsistent conclusions at the regional level from different EO studies could be related to differences in the spatial resolutions and generations of sensor, the study period, the applied remote sensing indices, and the assumptions and utilized computational methods.

In 2007, eleven African countries (Senegal, Mauritania, Mali, Burkina Faso, Nigeria, Niger, Chad, Sudan, Ethiopia, Eritrea, and Djibouti) adopted the **Great Green Wall for the Sahara and the Sahel Initiative** (GGWSSI) to tackle the adverse social, economic, and environmental impacts of desertification in the region. These countries agreed to join forces in a pan-African reforestation project with the ambition of creating a continuous series of restored ecosystems across the African continent from east to west, in total more than 7000 km. The initial idea has evolved from a tree wall to a vision of mosaic interventions addressing the challenges of the local population. Overall, the GGWSSI aims at strengthening the resilience of the natural systems and the region's people by thorough ecosystem management and improved living conditions of the population. The GGWSSI supports initiatives of local communities for the sustainable management of rangelands, forests and other natural resources. In addition, it aims at improving the food security in the region and contributing to climate change mitigation and adaptation. In 2012, the African Ministerial Conference on Environment adopted a harmonized strategy for the GGWSSI (African Union & Panafrican Agency of the Great Green Wall 2012). Today many Sahelian and Saharan countries (Algeria, Burkina Faso, Chad, Djibouti, Egypt, Eritrea, Ethiopia, Gambia, Mali, Mauritania, Niger, Nigeria, Senegal, Sudan) as well as different international partners, organisations of the United Nations, non-governmental organisations, and the scientific community are involved in the GGWSSI, including the European Union Delegation to the African Union Commission (e.g., <http://www.greatgreenwallinitiative.org/>).

The GGWSSI has received considerable attention in the international arena as a potential game-changer for improving livelihoods and resilience in the Sahel. However, the success of the GGWSSI will depend on its capacity to intelligently gather, generate, integrate, and use knowledge derived from a wide range of disciplines, taking into account the nature and complexity of socio-ecological systems. In Senegal, several projects (e.g., reforestation, forage, and community gardens) have been implemented in the context of the GGWSSI by the Great Green Wall agency under the responsibility of the ministry of Environment, which concentrates funds for rehabilitation of soils and reforestation in a zone of Senegal. However the technical rationale for the selection of projects and the complete description of the projects itself (where, what, how, success

rate, etc.) is, to our knowledge, not available. In the case of the Senegalese activities under the GGWSSI referred to in this study, there was no direct funding by the European Union (EU). Even though in the context of cash for work projects implemented by World Food Programme (WFP) in partnership with the National Agency for the Great Green Wall, the EU provided indirect funding under the Food Facility programme.

The French research organization CNRS recently started a project (*Future Sahel* – Multi-scale approaches for the best resource management practices of Sahelian landscapes in the Great Green Wall for the Sahara and Sahel Initiative context; <http://future-sahel.blogspot.it/>) to address this information gap. Future Sahel aims to investigate on-the-ground, pragmatic resource management solutions (gather and generate), provide a conceptual framework to aid the decision making process within the GGWSSI project (integrate), and with the Senegalese National Great Green Wall Agency as a partner, translate research into direct action (use). In preparation of the Future-Sahel project, a mapping campaign of the western part of the GGWSSI transect in Senegal has been undertaken documenting the location and outline, type, and date of GGWSSI and other projects in this area (Mauclaire 2014).

1.2 Objectives of the study

Different interventions in various environmental and social settings are implemented within the GGWSSI to support the sustainable management of natural resources. In order to assess the usefulness and impact of these interventions for improved future planning and also as a feedback to the donors, a monitoring of the project interventions is necessary. On-site monitoring is often very time-consuming and costly. Therefore, a remote system would be desirable to support the monitoring process of the physical impact (e.g., with rapid assessment of certain parameters over large areas/many projects to guide the selection of projects for on-site in-deep assessment).

The objective of this study is to utilize a biophysical indicator obtained via satellite imagery and compare the difference between project sites and corresponding reference sites before and after the intervention. Besides this specific comparison between project and reference sites, the general state and development of vegetation and other parameters (like precipitation) on a larger scale are important information for project planning in general and the project impact assessment. Therefore, time series of satellite-derived precipitation and vegetation data are analysed for general characteristics and trends.

In this study, north Senegal (Figure 1) was chosen as a study area as information on several GGWSSI projects (location, time and kind of intervention) were available through collaboration with the CNRS team. The mean and different linear trend estimators were calculated for annual precipitation sums and a seasonal vegetation indicator to characterize regional precipitation and vegetation development for the period 2001–2014 (and 1981–2014 for precipitation). Regarding the impact assessment, several satellite imagery with different spatial and temporal resolution (eMODIS, Landsat, google imagery) as well as several methods with varying complexity were tested to evaluate the impact of project interventions based on a biophysical parameter (greening as a proxy for biomass increase). The present report focuses on the precipitation and vegetation analysis and presents some first simple tests for the physical impact assessment, while an upcoming scientific paper will present a more advanced and more automatic approach.

2. Study area, data and methods

2.1 Study area

The northern part of Senegal is selected as case-study for the regional precipitation and vegetation analyses as it comprises the GGWSSI area and some information are available on several GGWSSI projects (Figure 1). The study area is characterized by a hot arid desert climate in the north (BWh) and a hot arid steppe climate (BSh) in the South (according to the updated Köppen-Geiger climate classification; Kotttek et al. 2006). The annual mean near-surface temperature is $\geq +18^{\circ}\text{C}$ and the mean annual precipitation is ranging from <200 mm in the north to about 600 mm in the southeast (1981–2014; Figure 5, top). The majority of precipitation is falling during the rainy season and is related to the West African Monsoon (Nicholson 2013). Annual precipitation sums are characterized by a high inter-annual and decadal variability being typical for the entire Sahel. Figure 2 shows the annual precipitation anomalies for the Sahel for the period 1900 to 2013 highlighting persistent drought conditions in the 1970s and 1980s and some degree of recovery since then. This past precipitation development is important to keep in mind as many RS-based studies on vegetation development start after the extreme dry conditions of the 1980s and do therefore identify positive vegetation trends.

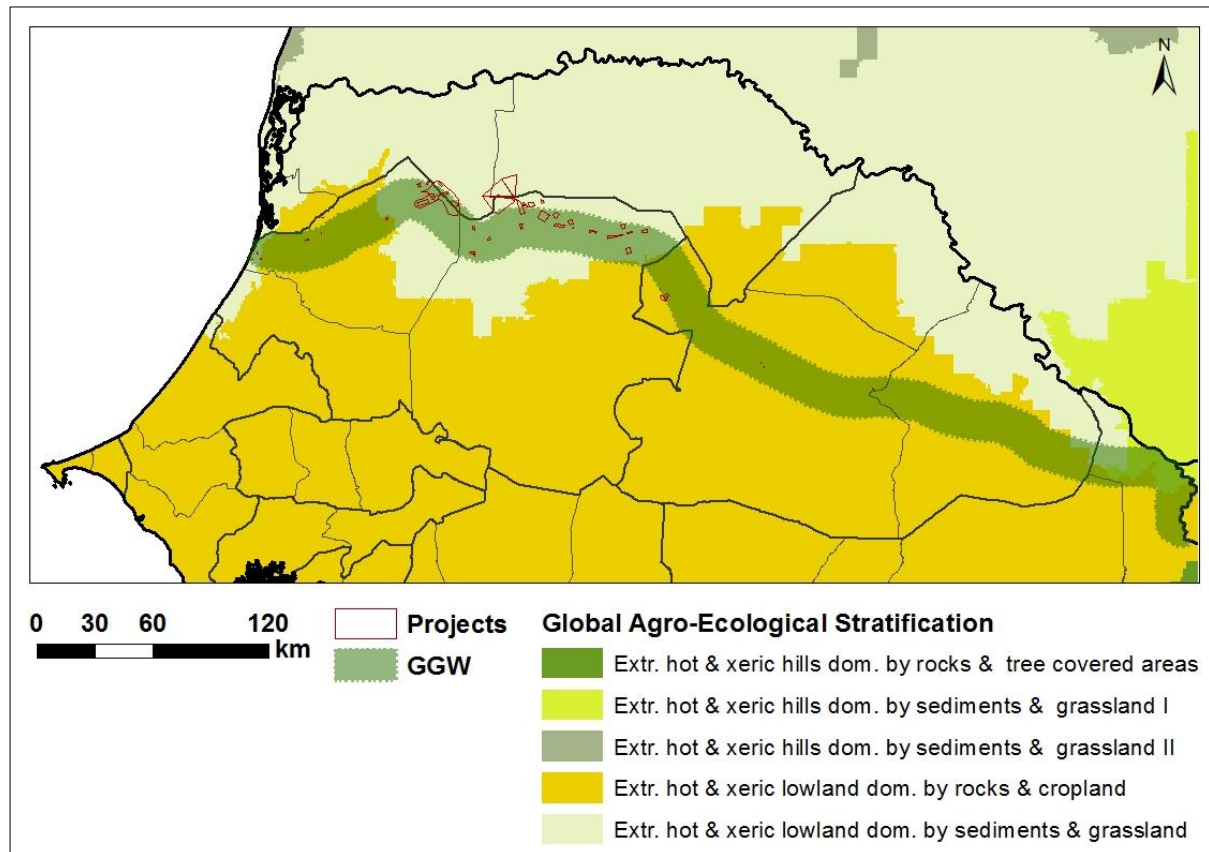


Figure 1. Study area with outline of GGWSSI in Senegal and projects mapped by CNRS overlaid on Global Agro-Environmental Stratification, level 4 (Mücher et al. 2016)

The GGWSSI area in Senegal belongs mainly to the Sahelian acacia savannah ecoregion while the south of the study region is dominated by the West Sudanian savannah ecoregion (Olsen et al. 2001). With respect to the Global Agro-Ecological Stratification (GAES; Mücher et al. 2016) the study area belongs mainly to the extreme hot and xeric

lowlands dominated by rocks and cropland (in the south) or dominated by sediments and grassland (in the north).

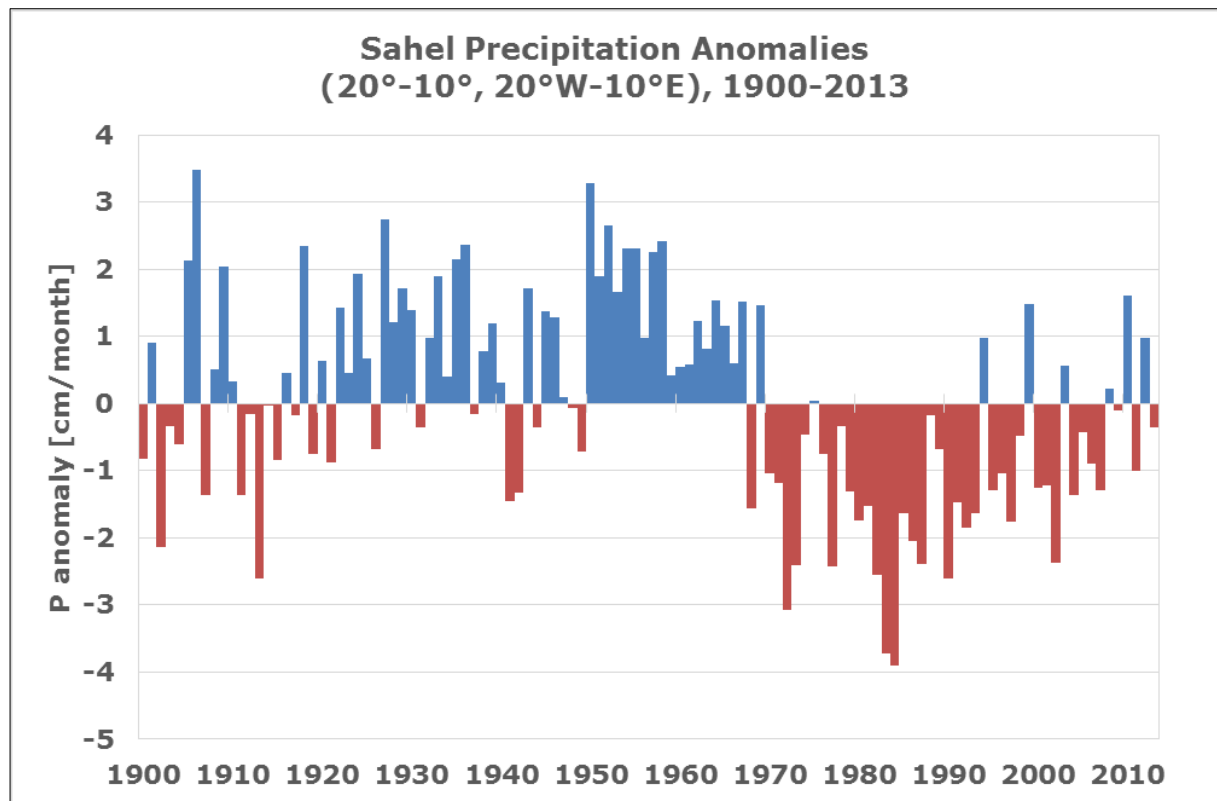


Figure 2. Sahel precipitation anomalies for 1900–2013 with respect to 1900–1930 (June through October averages over 20°–10°N, 20°W–10°E based on NOAA NCDC Global Historical Climatology Network data; taken from http://research.jisao.washington.edu/data_sets/sahel/; doi:10.6069/H5MW2F2Q)

2.2 Regional precipitation and vegetation analysis

The regional precipitation and vegetation analysis was performed on a north Senegal window (17.6°W to 11.9°W, 14.2°N to 16.8°N). The study period was set to 2001–2014 corresponding to the start of the vegetation data set. Additionally, we included the period 1981–2014 for precipitation analysis (corresponding to the start of the used precipitation data set) to access the long-term development.

Precipitation. The gridded Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) rainfall dataset (Funk et al. 2015) was utilized for the regional precipitation analysis. CHIRPS incorporates 0.05° resolution satellite imagery with in-situ station data trying to overcome the drawbacks of rainfall estimates purely derived from satellite data (biases due to complex terrain often underestimating extreme precipitation events) and the ones produced only from station data (problems in regions with few rain gauge stations). After cumulating the 10-day data to annual precipitation sums, the long-term average, standard deviation (SD) and coefficient of variation ($CV = (\text{mean}/SD * 100)$), different linear trend estimators (ordinary least square slope – OLS slope; Mann-Kendall tau – MK τ) and corresponding p-values were calculated for the annual precipitation. Note that the OLS slope indicates the average variation of the considered variable over the study period assuming a linear variation. The OLS slope gives the rate of change per time step expressed in the same physical units as the considered variable. The monotonic Mann-Kendall trend represents a non-parametric trend indicator measuring the degree to which a trend is consistently decreasing or increasing. The Mann-Kendall statistic (MK τ) is calculated by evaluating all pair-wise combinations of

values over time at each pixel counting the number of decreasing or increasing with time. MK τ is the relative frequency of decreases minus the relative frequency of increases and ranges from -1 to 1.

Vegetation. The analysis of vegetation dynamics was based on the Normalized Difference Vegetation Index (NDVI) from 10-day eMODIS data (USGS 2013) with a spatial resolution of 250 m. This medium spatial resolution dataset was used as it offers a high temporal resolution allowing to calculate seasonal parameters in contrast to high spatial resolution datasets that often have a lower temporal resolution. The data was obtained from Famine Early Warning Systems Network (FEWS NET) data portal (<http://earlywarning.usgs.gov/fews/>). 10-day NDVI values were aggregated to annual values by computing the mean NDVI of the 36 dekads of each year. Mean, SD and CV were calculated for the mean annual NDVI.

Seasonality parameters of NDVI time series for each year were calculated with the TIMESAT software (Jönsson & Eklundh 2002, 2004; Eklundh & Jönsson 2015). Start (SOS) and end of the season (EOS) were defined as 20% of the amplitude of the fitted NDVI curve). If the TIMESAT algorithm is not able to detect a season in a certain year, all seasonal parameters for the respective year are set to zero. This could introduce a bias in the trend analysis of certain parameters (e.g. for the large integral and the maximum value). Therefore, we just used the small integral (sInt) of the growing season from the TIMESAT results, for which we assume negligible effects in the case of a not detected season. The small integral represents a proxy for the above-ground biomass production (Figure 3). In addition, we calculated the maximum NDVI (maxNDVI) for each year from the original eMODIS time series as a proxy of maximum vegetation development experienced over the growing season. For these two selected seasonal parameters mean, SD, and CV were calculated as well as different trend estimators (OLS slope, MK τ) with the corresponding p-value.

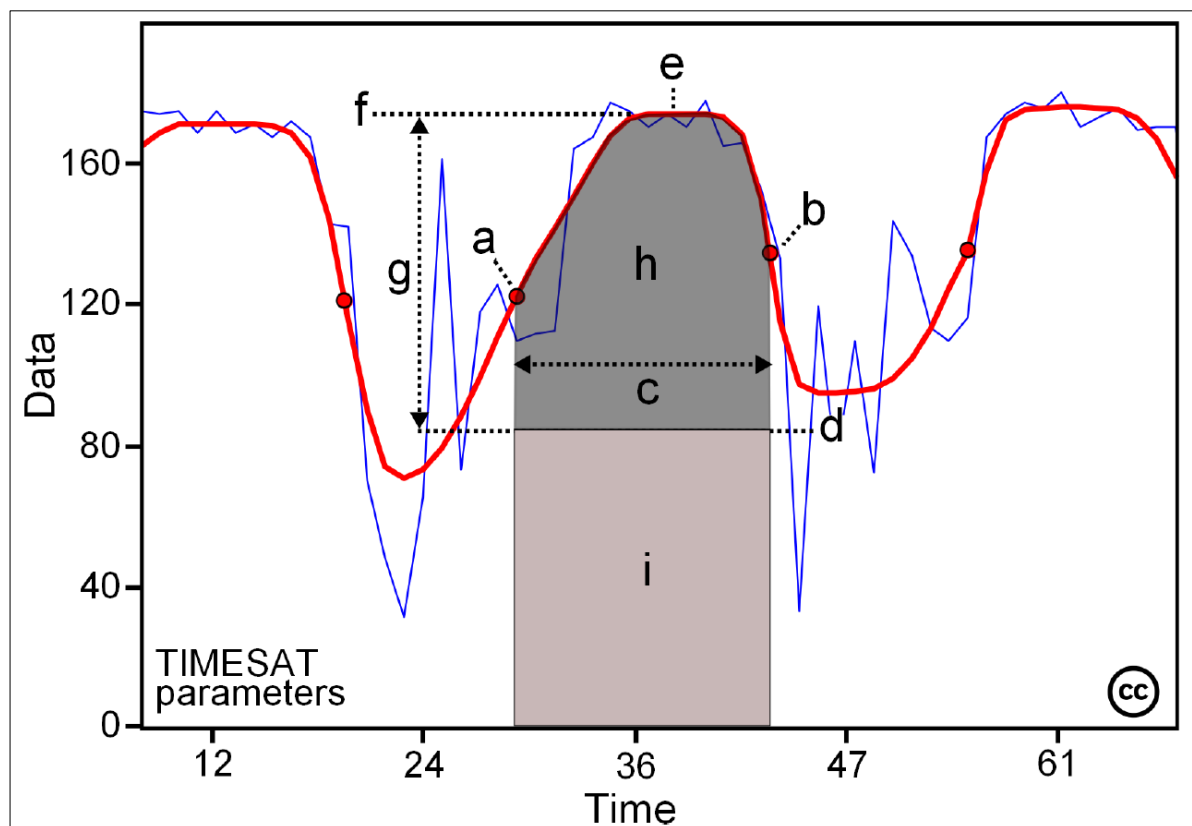


Figure 3. Some of the seasonality parameters generated in TIMESAT: (a) beginning of season, (b) end of season, (c) length of season, (d) base value, (e) time of middle of season, (f) maximum

value, (g) amplitude, (h) small integrated value, (h+i) large integrated value (Eklundh & Jönsson 2015)

Image processing and basic statistics were done with the SPIRITS software version July 2015 (Eerens et al. 2014; Rembold et al. 2015) and ENVI version 5.0.3 (Exelis Visual Information Solutions 2013). For the trend analysis the R software (R Development Core Team 2008) was used and for map creation QGIS version 2.8 Wien and version 2.14 Essen (QGIS Development Team 2015).

2.3 Multi-scale remote sensing based approach for impact monitoring

In order to monitor the biophysical impact of a restoration or sustainable agriculture/rangeland project we aim to develop a RS-based approach that may assist the evaluation of these kind of projects. In this study impact monitoring refers to a greening (proxy for biomass increase) that can be detected with medium to high resolution satellite imagery.

The idea is to compare project sites with reference sites before and after the intervention (Before-After Control-Impact Analysis, BACI) to evaluate if the intervention led to an increase in biomass in the project site. Several satellite imagery with different spatial and temporal resolution (eMODIS, Landsat, Google imagery) as well as several methods with varying complexity were tested. In this document we will focus on first, very basic tests. The more advanced methodology (proper BACI design) will be covered in an upcoming paper.

2.3.1 Visual assessment of project areas and surroundings

A first, very simple assessment of possible differences between project sites and their surroundings was done via visual inspections of two satellite data sets. On the one hand, very high resolution Google Earth imagery (Map data: Google, DigitalGlobe and CNES/Astrium) was utilized. The "show historical imagery" function in Google Earth was used to verify if images before and after the interventions are available for the different projects mapped by CNRS and if these images show any indication for a change within the project site compared to the surrounding area.

On the other hand maps with statistical measures (mean, SD, trends) derived from eMODIS 10-day NDVI data from 2001–2014 were visually inspected for differences between the project sites and the surroundings.

2.3.2 First tests of difference analysis between project and reference areas

Eleven project sites from the mapped projects of CNRS (Mauclaire 2014) were selected for first simple difference tests based on eMODIS 10-day NDVI data (2001–2014). Criteria for the selection were the size of the plot (a certain minimum size is required in order to extract valid statistics from medium-resolution imagery) and the year of the intervention (as eMODIS data need to be available some years before and after the intervention, projects implemented near the beginning or end of the MODIS observation period were discarded). Table 1 provides basic information on the selected projects like the type and the year of intervention as well as the size of the plot.

The reference sites (one per project site) were visually selected and delineated using very high resolution background maps (Bing Areal and Google Imagery) in QGIS. The reference sites have the same shape and size as the project sites and were placed in areas visually looking as much similar as possible to (and spatially close to) the corresponding project sites, not including villages or other infrastructures (Figure 4). As

this expert-guided selection of the reference sites is subjective, a more advanced selection approach will be developed in a future BACI design analysis.

Following the selection of the reference sites, areal means of the parameter maxNDVI (a proxy of maximum vegetation development experienced over the growing season) were extracted for all years of the period 2001–2014 for the project and reference areas. Then the difference between each project and the corresponding reference site was calculated for each year. Figures displaying the time series of maxNDVI (for project and reference site) and the difference between project and reference site were visually compared.

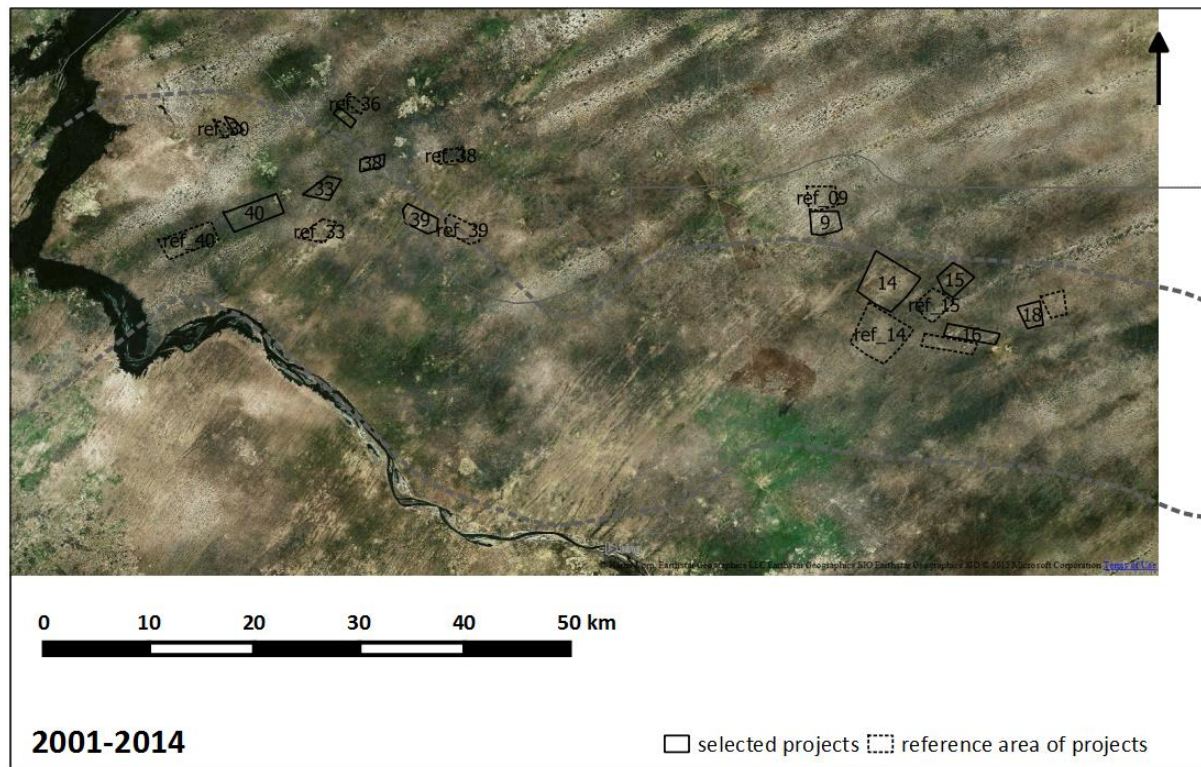


Figure 4. Location of selected project and reference areas (Map data: Bing, ©Harris Corp, Earthstar Geographics LLC Earthstar Geographics SIO Earthstar Geographics; © 2016 Microsoft Corporation)

2.3.3 Systematic difference analysis (before-after control-impact analysis)

The BACI design analysis will not be covered in this report and the reader is referred to the upcoming scientific paper. In general, the idea is to use an automated selection of reference sites (multiple reference sites per each single project site) and test if there is a statistical significant effect of the intervention in the project sites compared to the reference sites. A mixed effect linear model is used to assess this so-called BACI effect. For a detailed and practical introduction to BACI designs for ecological studies see Schwartz (2015).

Table 1. Some characteristics of selected project sites for the difference analysis.
Intervention: R = reforestation, F = forage, G = gum, Rs = reserve, U = under protection

ID	Intervention	Date	Area [km ²]	VHR image	VHR years	Difference images before/after	VHR	Project area compared with surroundings			
								annual mean NDVI	mean 10d NDVI	maxNDVI	slnt
9	R, F, G	2007-2008	6.1	no				mean, SD & CV higher	mean, SD & CV higher	OLS slope and MK τ more positive; mean higher	
14	R, Rs	2009-2010	20.0	no				mean, SD & CV higher	mean, SD & CV higher	OLS slope more positive; mean & SD higher	OLS slope more positive; mean and SD higher
15	R, F	2009-2010	6.7	partly	2005, 2014	no change visible		(mean, SD & CV higher)	mean, SD & CV higher	OLS slope and MK τ more positive; mean & SD higher	OLS slope and MK τ more positive; mean and SD higher
16	R, F	2009-2010	6.0	partly	2005, 2014	plantations visible		SD higher			
18	F	2009-2010	4.5	yes	2005, 2014	plantations, colour shift visible		SD higher		OLS slope and MK τ more positive	OLS slope and MK τ more positive; mean and SD higher
30	U	2004	1.3	no							
33	U, R	2011	4.5	no						OLS slope more positive;	(OLS slope and MK τ more positive)
36	R, F	2010	1.8	yes	2003, 2006, 2013	plough visible	trails				
38	R, F	2010	2.7	yes	2003, (2012), 2013	some visible	changes				
39	U	2011	6.0	no						(MK τ more positive)	
40	R, F	2010	10.9	no							

3. Results and Discussion

3.1 Regional precipitation and vegetation development

Precipitation

The general pattern of mean annual precipitation is similar for the two study periods 1981–2014 and 2001–2014 (Figure 5, top) showing a gradient roughly going from north (lower values) to south (higher values). Comparing the two study periods it seems that in general mean annual precipitation sums are higher in 2001–2014 compared to the long-term period.

The CV of annual precipitation is a measure for the inter-annual variability in relation to the mean annual precipitation. In general, areas in the north of the study area show a higher inter-annual variability than areas in the south (Figure 5, bottom) whereby the pattern differs a bit in the two study periods. Roughly speaking, areas with a low mean annual precipitation exhibit also a high inter-annual variability.

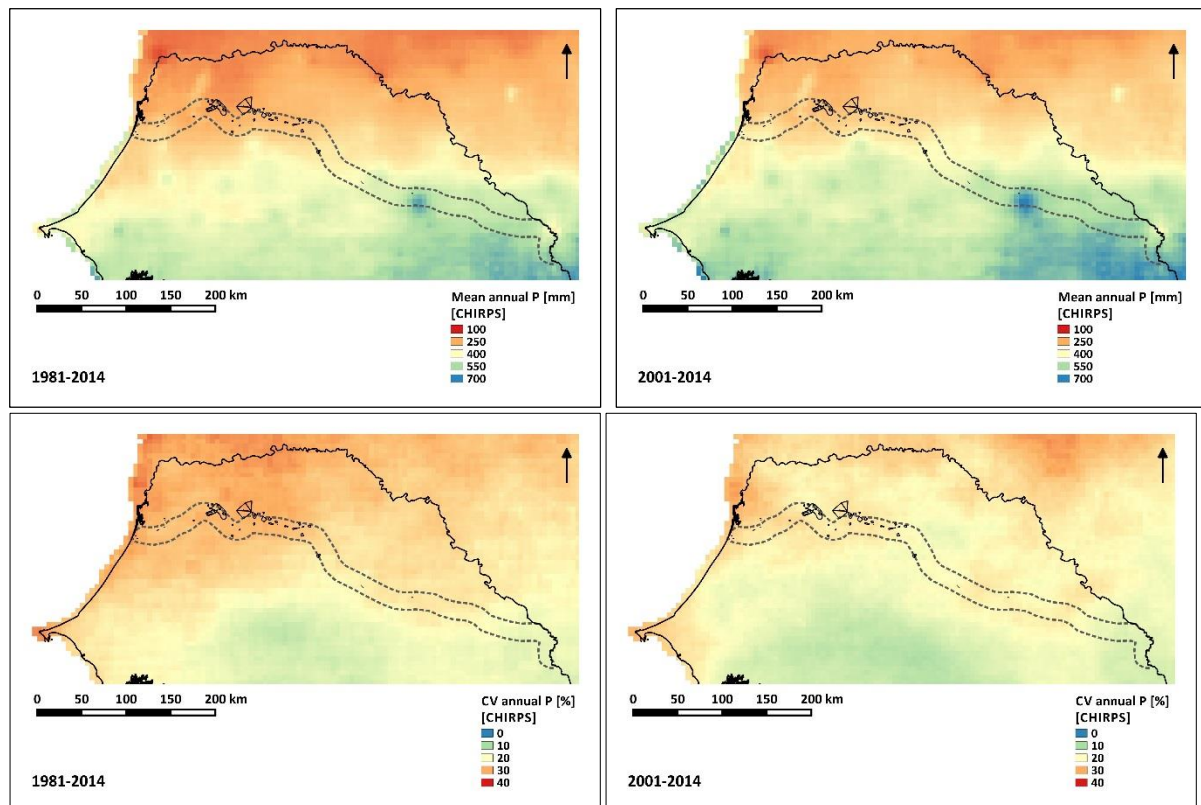


Figure 5. Mean (top) and coefficient of variation (CV; bottom) of annual precipitation for 1981–2014 (left) and 2001–2014 period (right) [based on CHIRPS data; Funk et al. 2015]

Over the 1981–2014 period, annual precipitation increased in the entire study area. The trend is significant (at a significance level of $\alpha = 0.95$) for most of the pixels (Figure 6) and reaches values of +100 to +200 mm (per 34 years) in the GGWSSI area. In general, both trend estimators (OLS slope and MK τ) show a similar spatial trend pattern (Figure A1). The precipitation increase in north Senegal is related to a precipitation recovery since the extreme dry periods of the 1970s and 1980s in the entire Sahel (e.g., Nicholson 2013 and references therein. See also Fig.2). However, according to Giannini et al. (2013) this recovery resulted from an increase in daily precipitation intensity rather than in increase in precipitation frequency.

In contrast to the long-term period, the recent shorter period (2001–2014) does not show any significant trend in annual precipitation (for OLS slope; for MK-tau very few pixels show a significant trend). To give an indication about precipitation development during this shorter and more recent period (although not significant for the 14 year period) the pattern of OLS slope and MK τ are provided in the appendix (Figure A2).

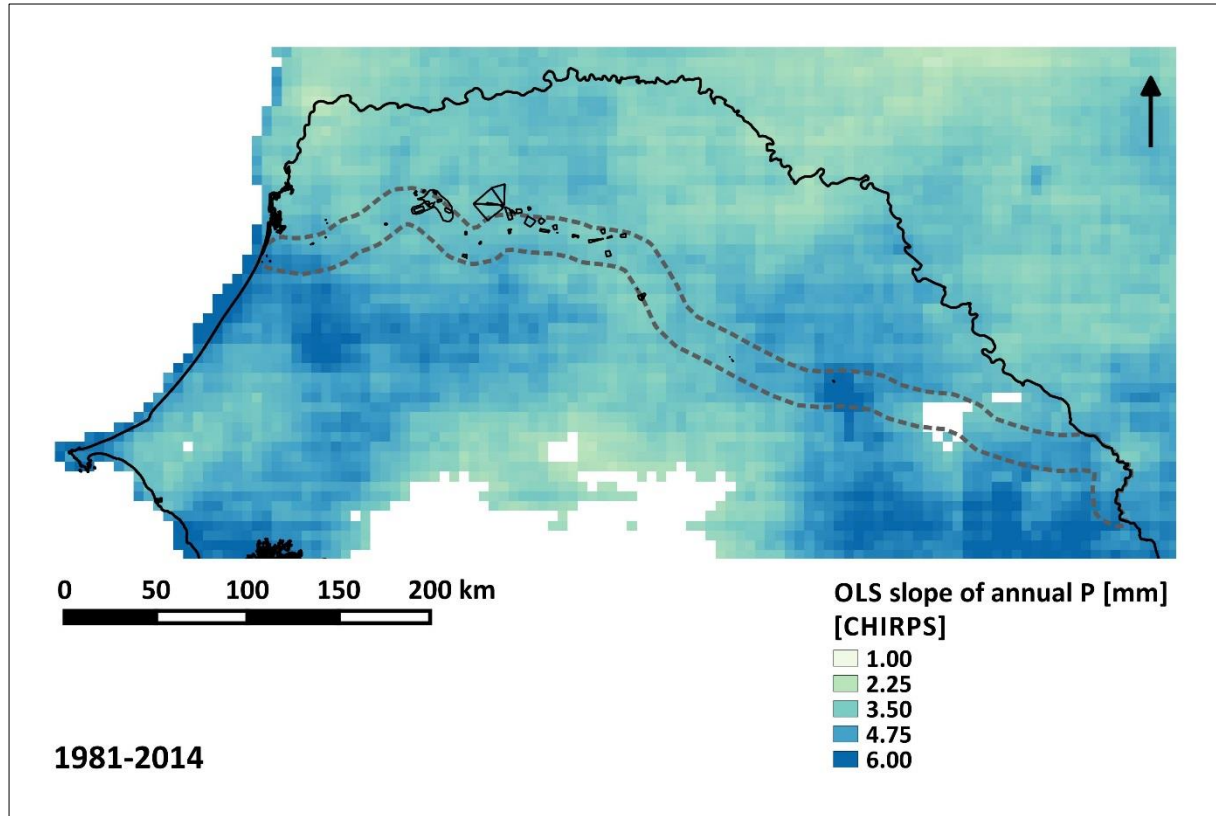


Figure 6. Trend (OLS-slope) of mean annual precipitation for 1981–2014 [based on CHIRPS data; Funk et al. 2015]. Only pixels with a statistically significant trend ($\alpha = 0.95$) are mapped.

Vegetation

The mean annual NDVI provides an indication about the average greenness across the year whereby denser and evergreen vegetation will have higher values than sparse and seasonal green vegetation. The CV of the annual NDVI in turn is a measure for the inter-annual variability of annual vegetation greenness where higher values indicate a higher difference between single years. The 2001–2014 mean of the mean annual NDVI of the study area (Figure 7, left) roughly shows a north-south gradient (with lowest values in the north) resembling the pattern of mean annual precipitation sums. Apart from this main pattern, some features (e.g., big cities, river beds) are clearly distinguishable from the surroundings. The inter-annual variability of annual NDVI represented by the CV (Figure 7, right) differs across the study area showing highest values in the north and central part of the study area. Note that also non-vegetated areas will show a low CV. The main spatial pattern of the mean of the seasonal parameters maxNDVI and sInt (Figure A3) are similar to each other and similar to the mean annual NDVI pattern.

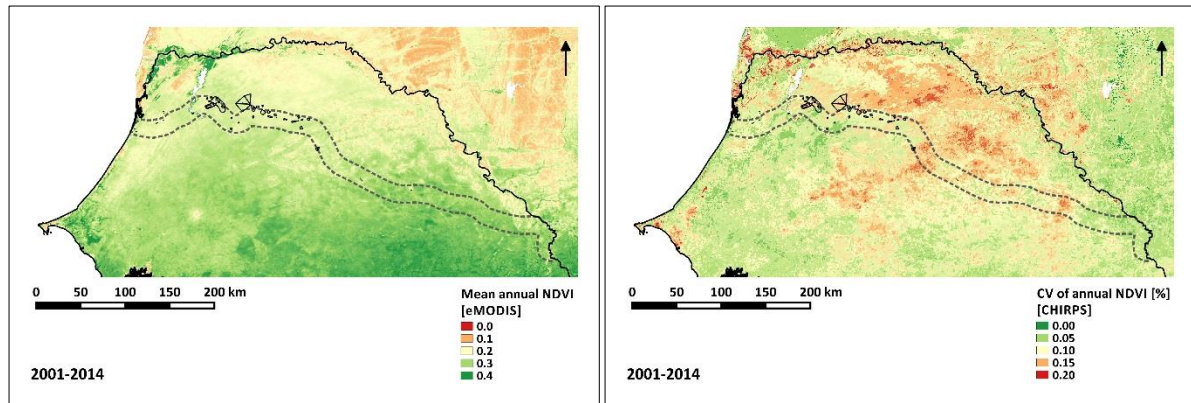


Figure 7. Mean annual NDVI: mean (left) and SD (right) for period 2001–2014 [based on eMODIS]

The trend pattern for both parametric (OLS) and non-parametric (MK τ) estimators were similar for both investigated seasonal parameters (maxNDVI, sInt; Figure A4). Therefore, we will just discuss the OLS slope in the following as this trend estimator has the same physical unit as the corresponding seasonal parameter.

The main trend pattern of maxNDVI and sInt are similar, but there are some local differences in certain areas (Figure 8; Figure A4, Figure A5). In other words, the choice of the seasonal parameter does not matter too much if one is interested in regional vegetation pattern, but it might be important for local assessments. Figure 8 shows the significant trends (at $\alpha = 0.95$) of maxNDVI and sInt indicating no clear change in most parts of the study area during 2001–2014. However, there are some trend hotspots – positive as well as negative ones. Positive trends in the seasonal parameters indicate an increase in biomass production (small integral) and maximum vegetation development (maxNDVI), respectively, while negative trends refer to a decrease in biomass production/maximum vegetation development.

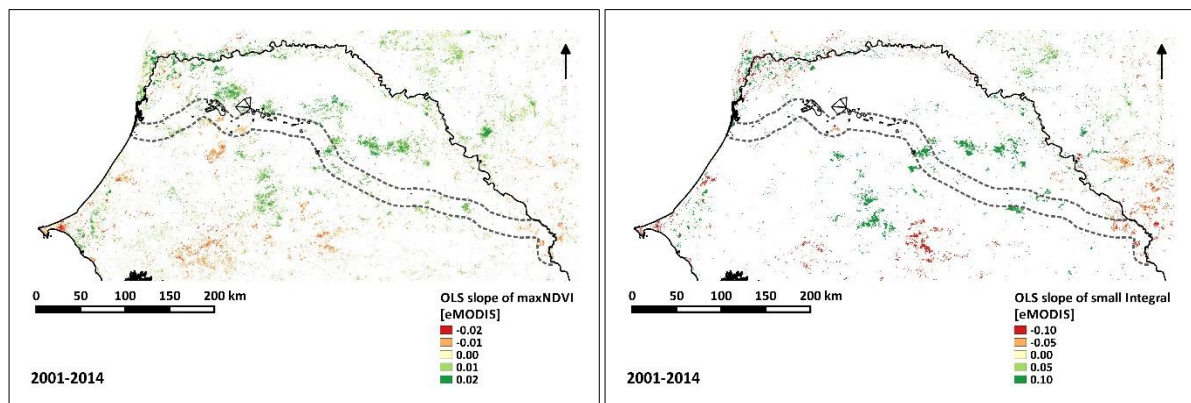


Figure 8. OLS slope maxNDVI (left) and sInt (right) for the period 2001–2014 [based on eMODIS]. Non-significant trends (at $\alpha = 0.95$) are masked out

More in-depth analyses (e.g. based on time series of very high resolution satellite imagery, field or other supplementary data) would be necessary to identify the causes of the vegetation trends. But this is beyond the scope of this report. In general we assume that precipitation changes could contribute to vegetation trends in places where there is a positive relationship between precipitation and the vegetation parameter and where precipitation and vegetation trends have the same trend direction. In the study area precipitation trends over the 2001–2014 period were not significant and are therefore assumed to be not the only potential driving factor for vegetation changes (if they play any role). Figure 9 shows areas where precipitation changes could partly explain

significant vegetation trends (related to maxNDVI) as they have the same OLS slope sign as maxNDVI. Areas in red represent regions with a negative OLS slope (negative trend) for precipitation and maxNDVI while green areas are characterised by a positive OLS slope of precipitation and maxNDVI. Grey areas show an opposite OLS slope (either negative P and positive maxNDVI or positive P and negative maxNDVI). For the GGWISS belt in Senegal, most significant vegetation trends are in line with the precipitation development (which is not significant). Therefore, precipitation change could be a partial cause of the vegetation trends in these regions.

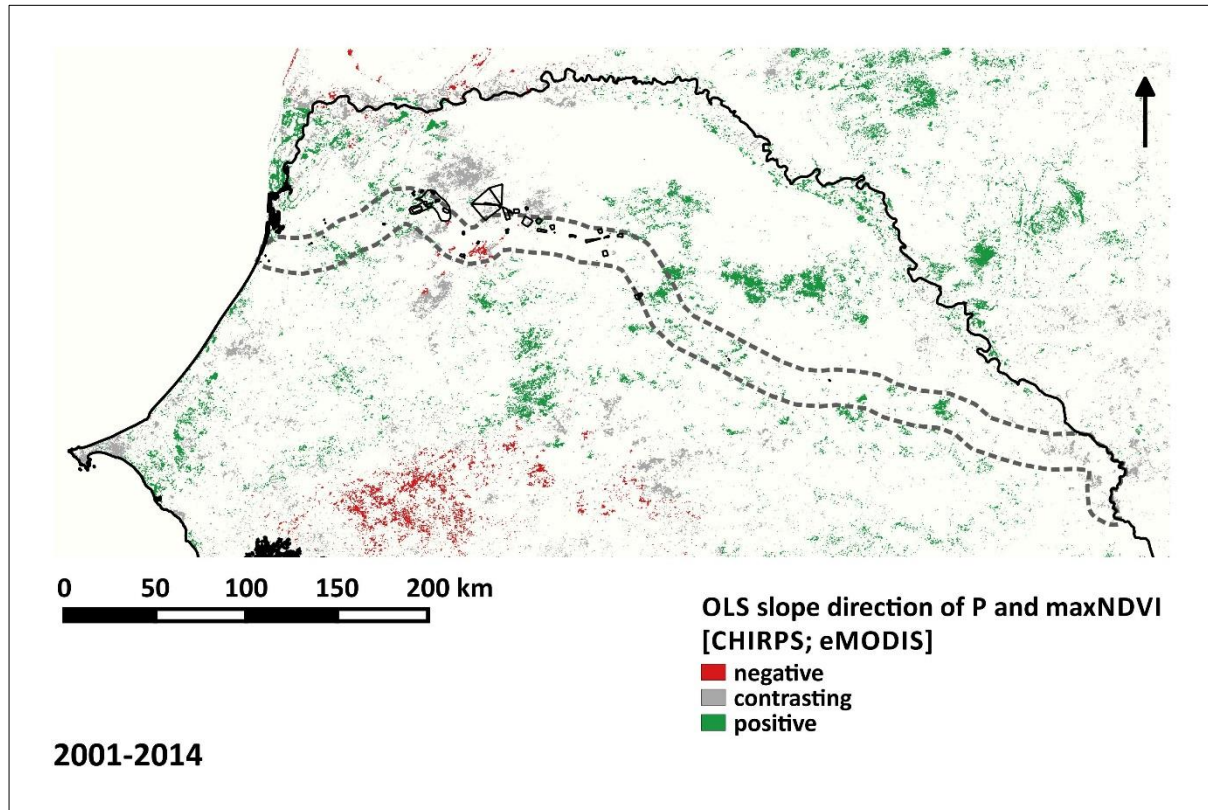


Figure 9. Overlay of OLS slope direction of precipitation and maxNDVI. Areas with no significant maxNDVI trend (at $\alpha = 0.95$) are masked out [based on eMODIS and CHIRPS]

3.2 Biomass impact monitoring

3.2.1 Visual assessment of project areas and surroundings

Very high resolution (VHR) images in Google Earth before and after the intervention are just available for 14 out of 62 projects (Appendix 7). For those project sites, where VHR were available before and after the intervention, it was visually assessed if there are any changes visible. The results and the year of the available VHR images are presented in Table 1 (projects selected for difference analysis) and Table A1 of the appendix (all projects). For some projects changes were visible (e.g. plantations) for others not. In general, we assume that if there are no changes visible in the VHR images, it will not be possible to detect changes in high (Landsat) and medium-resolution (MODIS) images.

Following a visual inspection, many projects do not differ in environmental terms from their surroundings in the maps derived from eMODIS data (mean and SD of annual mean NDVI; mean and SD of 10d NDVI; mean, OLS slope and MK τ of maxNDVI and sInt) or were too small to be assessed with the medium-resolution data (Table 1, Table A1). Note that the maps derived from eMODIS cover the entire study period and do not

compare a before and after intervention period. This means that projects that were implemented late in the study period are unlikely to show any difference to their surroundings (although there might be an effect after the intervention). Project sites, where differences in one or more parameters compared to the surroundings were visible are ID9, ID14, ID15, ID16, ID18, ID32, ID33, ID39, and ID43. An example for such a difference is presented in Figure 10 showing higher mean annual NDVI for project ID9 and ID14.

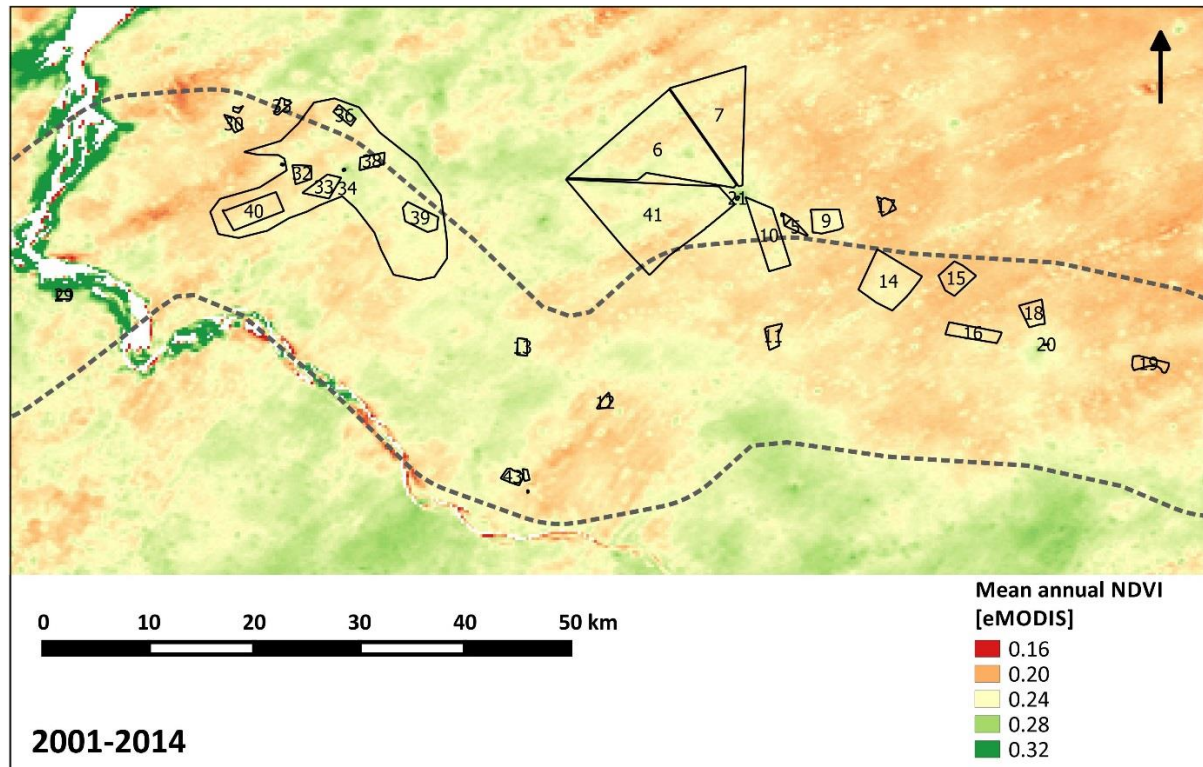


Figure 10. Mean annual NDVI for period 2001–2014 for sub-region [based on eMODIS]. Note the extremely dry nature of the project sites (NDVI<0.2 is generally considered as bare soil)

3.2.2 First tests of difference analysis

The time series of maxNDVI (Figure 12) were plotted for each project site (green line) and the corresponding reference site (red line) together with the difference between project and reference site (black line). For a better interpretation the time of intervention (arrow) is also indicated in the figures. The figures highlight the high inter-annual variability of maxNDVI. In general, project and reference site show a similar maxNDVI trajectory.

The visual inspection of the figures (Figure 12, see also multi-temporal very high resolution maps for each site in Appendix 7) revealed three main groups with respect to the temporal development of the difference between maxNDVI in project and reference sites:

- **Group 1** (4/11) showing no notable change of the difference after the intervention. This group includes sites ID16, ID30, ID36, and ID40 that all have a relative stable difference level over time.
- **Group 2** (5/11) showing a (slightly) higher average difference after the intervention (ID9, ID14, ID15, ID18, ID38). The difference is notably increasing in the first year after intervention and then tendentially decreasing for sites ID14, ID15, and ID38.

- **Group 3** (2/11) with a steady increase of the difference starting from the year after the intervention. But the maximum value before the intervention is not (ID33) or is just reached in the last year of observation (ID3)

As the observed changes in differences between project and reference site (or absence of a change) are based on visual analysis they need further refinement by more advanced analysis (including statistical tests).

In general, if there is no change visible in the difference between project and reference site in the years after the intervention, this could be due to a failure of the intervention. An increase in the difference between project and reference site after the intervention, followed by a later decreases could be an indication that the intervention was initially successful, but then the site developed back to the surrounding conditions (see site ID9 and ID38). Reasons for a failure of interventions could be manifold. For the case of reforestation a failure could be induced by the wrong choice of seedling time and seedling species, extreme weather event after the plantation, inappropriate choice of project site (e.g. due to adverse environmental conditions), missing follow-up of the plantation, missing protection of the seedlings, no involvement of local population etc. A field trip to some of the central GGWSSI projects in Senegal in October 2015 revealed that a top-down approach without involvement of the local population was chosen for the project implementation leading to a partial non-acceptance of the projects in the beginning. In some of the project sites plantations were less successful than in others. For example, the plantation digs in project ID33 (Figure 11, left) are still visible, but just few of the seedlings survived. In contrast, the planted trees in project ID15 (Figure 11, right) were generally in a good physical shape.



Figure 11. Impressions from project ID33 (left) and ID15 (right) taken in Oct 2015

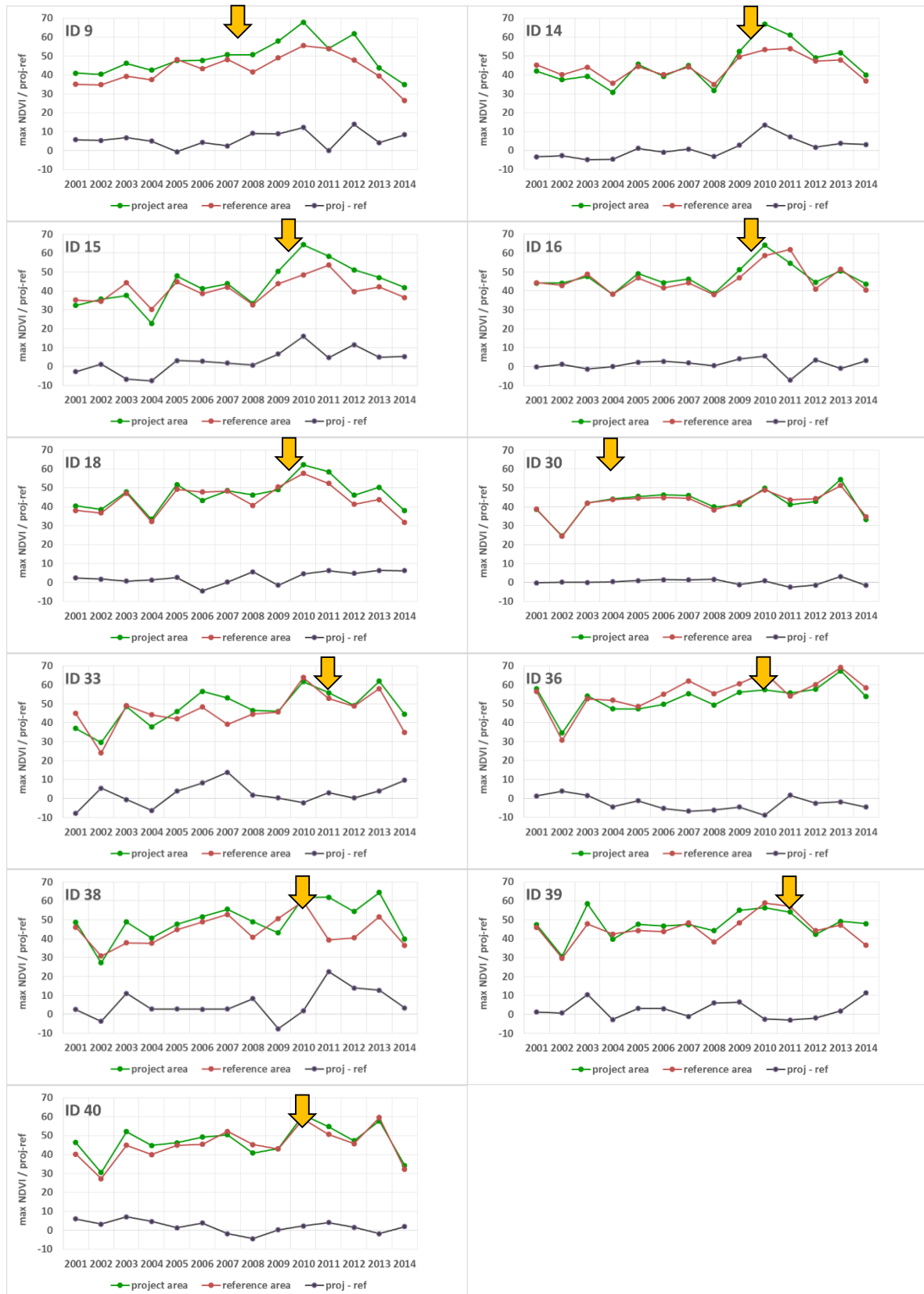


Figure 12. Temporal development of maxNDVI in project and reference areas for 2001–2014 [based on eMODIS]. Time of intervention (reforestation & forage, except for: ID18, ID39 – forage; ID30 – fenced for biodiversity) is marked with yellow arrows. NDVI with scaled axis (NDVI * 100)

4. Conclusions

In the context of the Great Green Wall for the Sahara and the Sahel Initiative (GGWSSI) and in the framework of the Technical and scientific Support to agriculture and Food and Nutrition Security (TS4FNS), this study presents a regional precipitation and vegetation analysis for north Senegal as a support for a remote sensing (RS) based biomass impact assessment of GGWSSI and other projects. This regional analysis is needed for better understanding of project specific impacts on biomass increase. The results of some first and basic tests on the impact assessment of several (mainly reforestation) projects are also shown.

Time series of remotely sensed precipitation (P) and Normalized Difference Vegetation Index (NDVI) data were utilised to characterize general precipitation and vegetation characteristics in the region and to compute long- (P) and short-term trends (P, NDVI). The results indicate a long-term increase in annual precipitation sums over the period 1981–2014 in the entire study area in agreement with other analyses of climate data. However, no significant precipitation trend could be detected over the short-term period (2001–2014). In a similar way the vegetation trends (2001–2014) based on NDVI-based indicators were not significant for most of the study area, but there were some local hotspots with a negative as well some hot spots with a positive vegetation development. We assume that for these hotspots, additional/other factors than changes in precipitation need to be considered in explaining the vegetation trends as the precipitation changes were not significant and sometimes even showed opposite signal. The results can be used as a first overview about recent precipitation and vegetation developments in the region, but further analysis would be necessary to assess local and regional vegetation changes and potential drivers more in-depth. Future studies could for example include other sources of information (e.g. longer-term RS-based vegetation data (with coarser resolution), field studies, interviews with local people). The rapidly increasing availability of high resolution earth observation data, such as those provided by the EU funded Sentinel program is contributing to an increased potential of monitoring methods based on Earth Observation.

Basic impact assessment for selected restoration projects (within the GGWSSI) on above-ground biomass were performed, based on visual inspection of very high resolution images before and after the intervention and simple difference analysis between project sites and reference sites. For some projects, slight changes after the intervention could be observed. However, these changes seem small and for some projects we could not detect any improvement at all of the project sites compared with the reference sites. It is important to remember though that the increase of woody biomass should not be used as the only indicator for measuring project success. First, some of the projects are part of cash for work programs and woody biomass increase is not their only objective. Second, there might be other positive effects for local populations, such as for example a higher availability of grass inside fenced areas during drought periods.

Finally it is clear that the method of biophysical impact assessment needs some further development (which is in progress) in order to be more objective and statistically representative. Also more sites would be necessary for more complete testing of the method under different environmental conditions. Further analysis (including field visits) to verify the signals of failed intervention are recommended where the advanced methodology will not show any remarkable improvement of certain project sites compared to references sites. In case of a failure, it would be highly interesting to analyse the various reasons. Learning from past unsuccessful projects could lead to improved project planning and management.

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List of abbreviations

α	significance level
BACI	before after control impact
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station data
EU	European Union
MODIS	Moderate-Resolution Imaging Spectroradiometer
GGWSSI	Great Green Wall for the Sahara and the Sahel Initiative
FEWS NET	Famine Early Warning Systems Network
maxNDVI	maximum NDVI during the growing season
MK	Mann Kendall
MODIS	Moderate Resolution Imaging Spectroradiometer
NDVI	normalized difference vegetation index
OLS	ordinary least square
P	Precipitation
RS	remote sensing
SD	standard deviation
sInt	small integral over the growing season
TS4FNS	Technical and scientific Support to agriculture and Food and Nutrition Security
VHR	very high resolution
WFP	World Food Programme

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Appendix 1 – Project site information

Table A1. Information of projects mapped by the team of Deborah GOFFNER. Interventions: A=common agriculture, Af=agricultural farm, B=experimental site for bioenergy, F=forage, G=gum, M=multi-purpose garden, P=protected zone, Pc=created pond, R=reforestation, Rs=reserve, U=under protection, W=wood

ID	Inter- vention	Organisation	Type	Date	Species	Area [km ²]	VHR image before+after	VHR years	Difference VHR images	Comparison with surroundings				Diffe. anal.
										annual mean NDVI	mean 10d NDVI	Max NDVI	sInt	
1	R	SOS Sahel	Clôturé	2011	Eucalyptus	0.003	yes	2003, 2011, 2014	change visible, not sure about improvement	too small for comparison with surroundings				
2	R	SOS Sahel	Clôturé	2012	Eucalyptus	0.008	yes	2003, 2011, 2014	new building	too small for comparison with surroundings				
3	R	CILLS	Non clôturé	2011	Prosopis	0.006	yes	2003, 2011, 2014	new building	too small for comparison with surroundings				
4	R, F	GMV	Non clôturé	2011		0.441	no							
5	R, F	GMV	Clôturé	2011		1.3	no							
6	R	Projet sénégal- allemand	Clôturé	1989		70.982	no							
7	R	Projet sénégal- allemand	Clôturé	1985- 1986		44.112	no							
8	Test	GMV	Clôturé	2013	Balanites	0.055	no			too small for comparison with surroundings				

ID	Inter- vention	Organisation	Type	Date	Species	Area [km ²]	VHR image before+after	VHR years	Difference VHR images	Comparison with surroundings				Diffe. anal.
										annual mean NDVI	mean 10d NDVI	Max NDVI	sInt	
9	R, F, G	GMV	Clôturé	2007- 2008	Balanites	6.117	no			Mean & SD higher	Mean & SD higher	OLS slope and MK τ more positive; (mean higher)		x
10	F	Projet sénégal- allemand	Clôturé	1981		14.478	no							
11	R, F	GMV	Clôturé		Balanites	2.65	no							
12		GMV	Clôturé	En cours		1.093	no							
13	R, F	GMV	Clôturé	En cours		1.536	no							
14	R, Rs	GMV	Clôturé	2009- 2010	Balanites	20	no			Mean & SD higher	Mean & SD higher	OLS slope more positive; mean & SD higher	OLS slope more positive; mean and SD higher	x
15	R, F	GMV	Clôturé	2009- 2010	Balanites	6.735	partly	2005, 2014	no change visible	(mean and SD higher)	Mean & SD higher	OLS slope and MK τ more positive; mean & SD higher	OLS slope and MK τ more positive; mean and SD higher	x
16	R, F	GMV	Clôturé	2009- 2010	Balanites	6.036	partly	2005, 2014	plantations visible	SD higher				x
17	R	GMV	Clôturé	2012	Balanites	1.921	no							

ID	Inter- vention	Organisation	Type	Date	Species	Area [km ²]	VHR image before+after	VHR years	Difference VHR images	Comparison with surroundings				Diffe. anal.
										annual mean NDVI	mean 10d NDVI	Max NDVI	sInt	
18	F	GMV	Clôturé	2009- 2010	Balanites	4.464	yes	2005, 2014	plantations, colour shift visible	SD higher		OLS slope and MK τ more positive	OLS slope and MK τ more positive; mean and SD higher	x
19	R, F	GMV	Non clôturé		Balanites	3.197	no							
20	M	GMV			Manguiers	0.052	partly	2005, 2014	some changes visible	too small for comparison with surroundings				
21	M	GMV				0.082	no			too small for comparison with surroundings				
22	M	GMV		2012	Oignons pdt mangues citrons goyaves	0.037	yes	2002, 2011, 2013, 2014	changes visible	too small for comparison with surroundings				
23	M	GMV		2014		0.102	no			too small for comparison with surroundings				
24	W	Eaux et forêts	Clôturé	1989- 1990		0.059	no			too small for comparison with surroundings				
25	U, R	Eaux et forêts	Clôturé	1988- 1989		0.061	no			too small for comparison with surroundings				
26	U, R	Eaux et forêts	Clôturé	1988- 1989		0.027	no			too small for comparison with surroundings				

ID	Inter- vention	Organisation	Type	Date	Species	Area [km ²]	VHR image before+after	VHR years	Difference VHR images	Comparison with surroundings				Diffe. anal.
										annual mean NDVI	mean 10d NDVI	Max NDVI	sInt	
27	U, R	Eaux et forêts	Clôturé	1988- 1989		0.014	no			too small for comparison with surroundings				
28	U	Projet Biodiversité	Non clôturé	2004		0.332	no							
29	Af	ANIDA			Oignons tomates piments verger	1.006	yes	2003, 2010, 2012, 2013	changes visible	no difference to surroundings				
30	U	Projet Biodiversité	Non clôturé	2004		1.292	no							x
31	M	GMV		2012	Balanites	0.049	no			too small for comparison with surroundings				
32	R, F	GMV	Clôturé	2013	Balanites	2.683	no						(MK τ more positive)	
33	U, R	GMV	Clôturé	2011	Nilotica senegal	4.533	no					OLS slope more positive	(OLS slope and MK τ more positive)	x
34	P	GMV	Non clôturé	2012		189.25	-			no difference to surroundings				
35	R, F	GMV	Clôturé	2014	Balanites	1.263	no							

ID	Inter- vention	Organisation	Type	Date	Species	Area [km ²]	VHR image before+after	VHR years	Difference VHR images	Comparison with surroundings				Diffe. anal.
										annual mean NDVI	mean 10d NDVI	Max NDVI	sInt	
36	R, F	GMV	Clôturé	2010	Radiana seyal balanites aegyptica	1.849	yes	2003, 2006, 2013	plough trails visible					x
37	M	GMV		2011		0.049	yes	2003, 2012, 2013	development of garden visible	too small for comparison with surroundings				
38	R, F	GMV	Clôturé	2010	Balanites	2.731	yes	2003, (2012), 2013	some changes visible					x
39	U	GMV	Clôturé	2011		5.958	no					(MK τ more positive)		x
40	R, F	GMV	Clôturé	2010		10.937	no							x
41	Pp	Projet sénégal- allemand	Clôturé			78.571	no							
42	M	GMV		2012	Manguiers citrons mandarines jubarina aubergines	0.036	no			too small for comparison with surroundings				

ID	Inter- vention	Organisation	Type	Date	Species	Area [km ²]	VHR image before+after	VHR years	Difference VHR images	Comparison with surroundings				Diffe. anal.
										annual mean NDVI	mean 10d NDVI	Max NDVI	sInt	
43	R, F	GMV	Clôturé	2012	Balanites	2.172	no					(SD lower)	(MK τ more positive)	
44	R, F	GMV	Clôturé	2010	Balanites	0.519	no							
45	R	GMV	Clôturé		Balanites	4.502	no							
46	Pc	GMV			Balanites	0.02	no			too small for comparison with surroundings				
47	M	GMV			Balanites	0.059	no			too small for comparison with surroundings				
48	R	GMV	Clôturé	2009- 2010	Balanites	1.369	no							
49	R	GMV	Clôturé		Balanites	4.334	no							
50	R	GMV	Clôturé		Balanites	6.388	no							
51	R	GMV	Clôturé		Balanites	6.854	no							
52	R	Projet acacias	Non clôturé		Acacias	0.38	no			too small for comparison with surroundings				
53	R	Eaux et forêts et villageois	Non clôturé	plus de 30 ans	Gommiers	0.004	no			too small for comparison with surroundings				
54	R	Eaux et forêts et villageois	Non clôturée	1990	Gommiers	0.015	no			too small for comparison with surroundings				
55	R	Eaux et forêts et villageois	Non clôturée	2013	Gommiers	0.088	no			too small for comparison with surroundings				

ID	Inter- vention	Organisation	Type	Date	Species	Area [km ²]	VHR image before+after	VHR years	Difference VHR images	Comparison with surroundings				Diffe. anal.
										annual mean NDVI	mean 10d NDVI	Max NDVI	sInt	
56	M	GMV		2014	Balanites	0.044	no			too small for comparison with surroundings				
57	R, F	GMV	Non clôturé	2009	Balanites	3.871	no							
58	R	GMV	Non clôturé	2009	Balanites	2.288	no							
59	R	GMV	Non clôturée	2009	Balanites	2.421	no							
60	Rs		Clôturé	2009		0.108	yes	2003, 2011, 2013, 2014	increase in tree biomass visible	too small for comparison with surroundings				
61	B	CILLS et UCAD	Clôturé		Jatropha	0.253	yes	2003, 2011, 2013, 2014	plantations visible	too small for comparison with surroundings				
62	A	Plan International		2002- 2003		0.285	no			too small for comparison with surroundings				

Appendix 2 – Precipitation trends

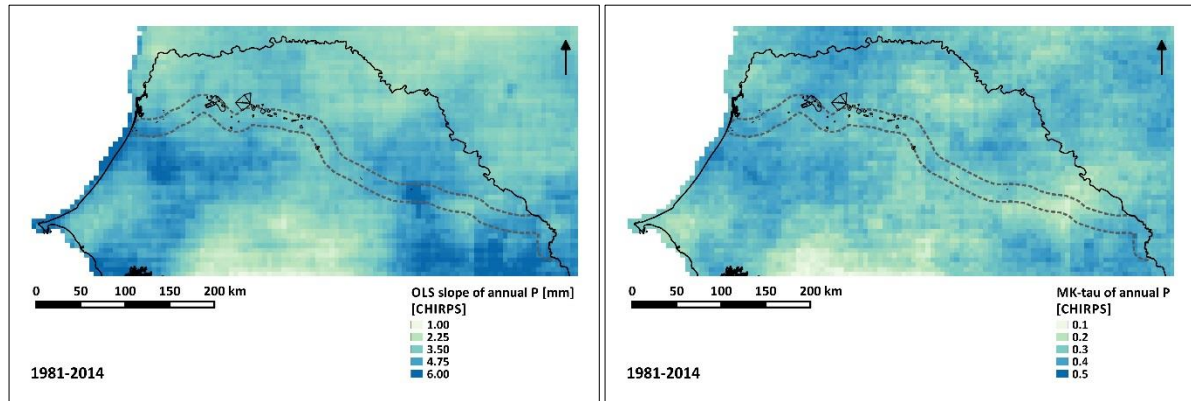


Figure A1. Trends of mean annual precipitation (left: OLS slope, right: MK τ) for 1981–2014 [based on CHIRPS data]. Note the trend is significant for most of the pixels at $\alpha = 0.95$

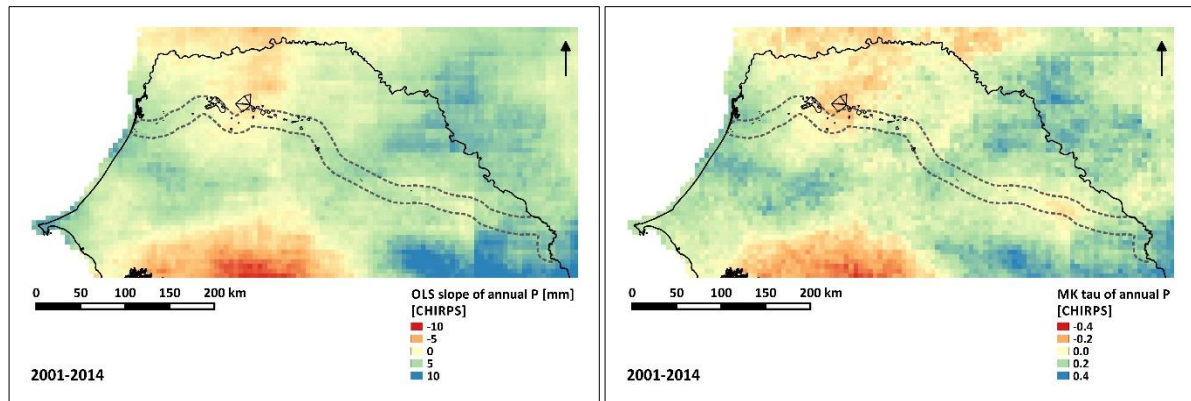


Figure A2. Trends of mean annual precipitation (left: OLS slope, right: MK τ) for 2001–2014 [based on CHIRPS data]. Note the trend is not significant for all (OLS-slope) or nearly all pixels (MK-tau) at $\alpha = 0.95$

Appendix 3 – Mean and SD of seasonal parameters

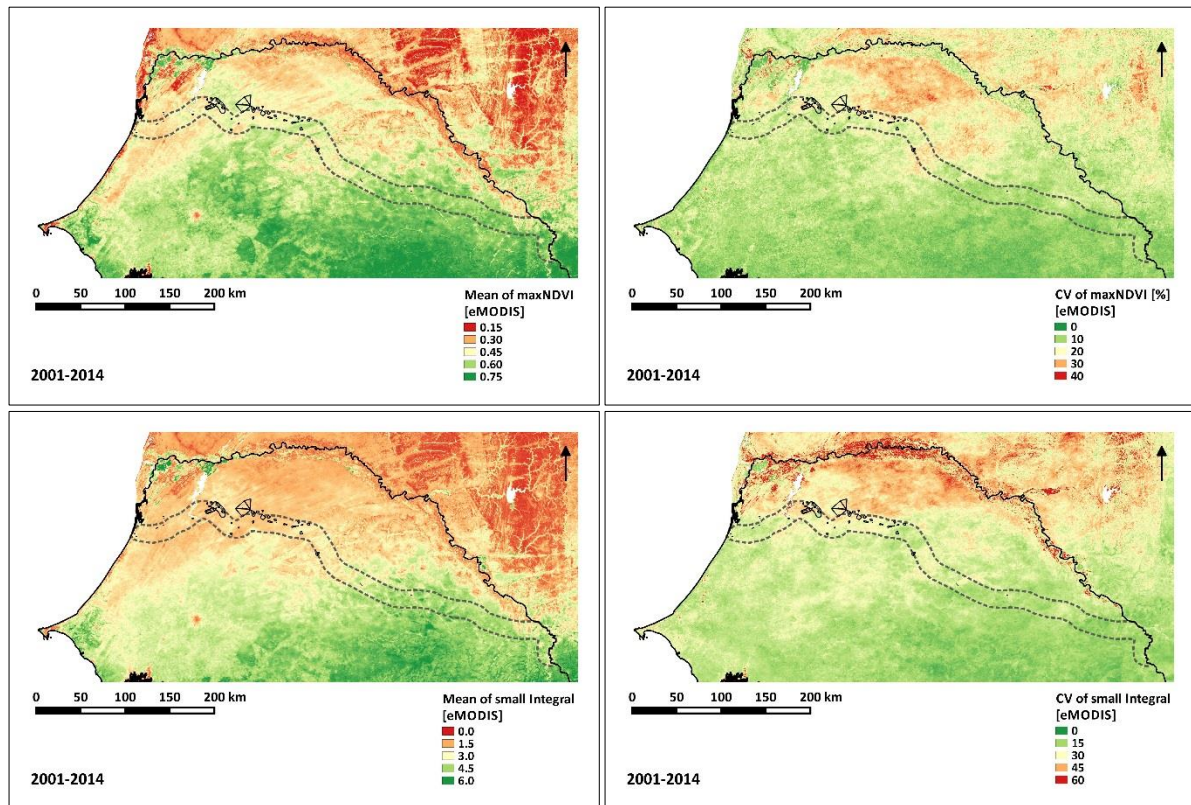


Figure A3. Mean (left) and CV (right) for maxNDVI (top) and sInt (bottom) for period 2001–2014 [based on eMODIS]

Appendix 4 – Trend pattern of seasonal parameters

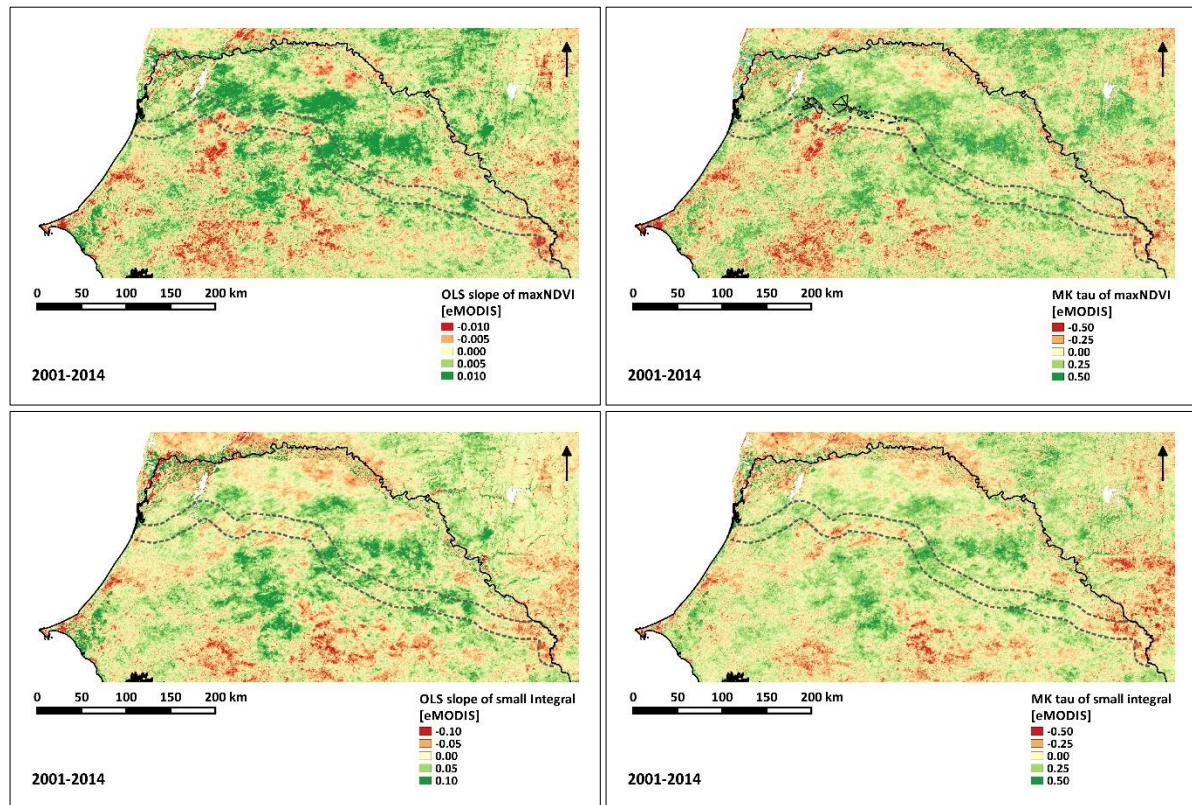


Figure A4. OLS slope (left) and MK-tau (right) for maxNDVI (top) and sInt (bottom) for period 2001–2014 [based on eMODIS]

Appendix 5 – Significant trends of seasonal parameters

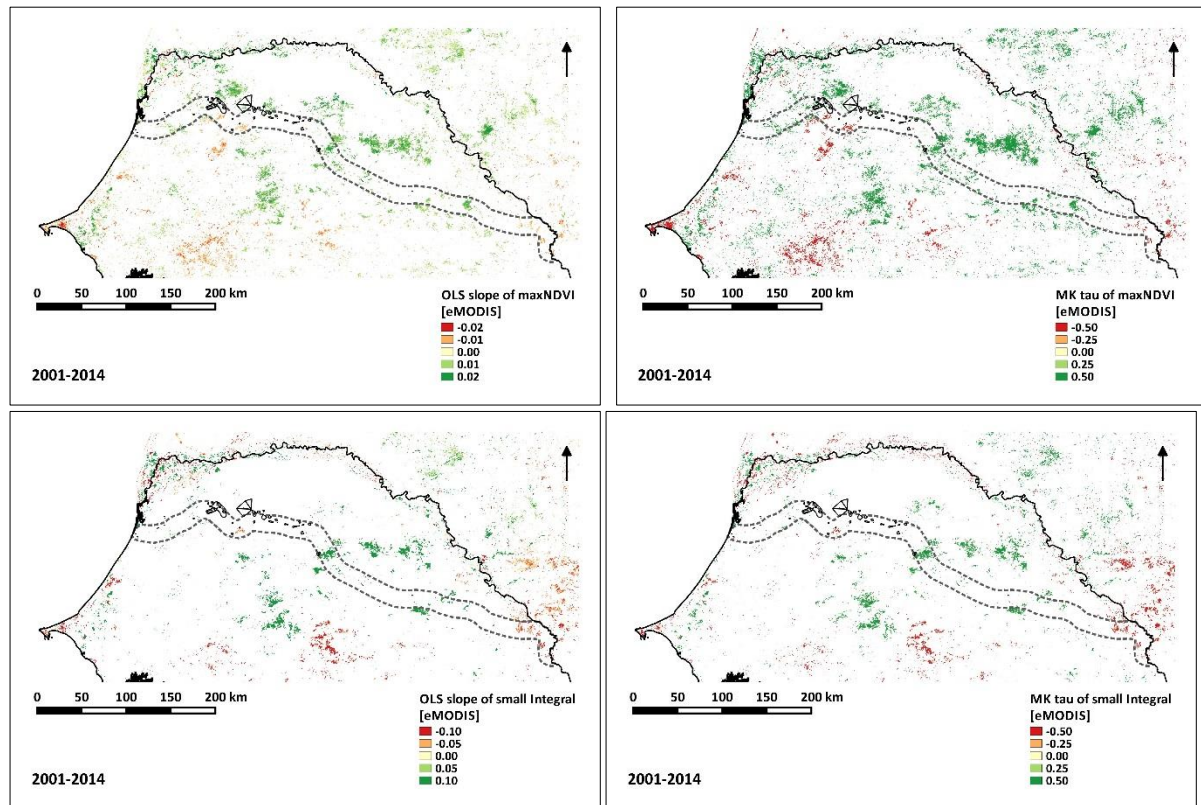


Figure A5. OLS slope (left) and MK-tau (right) for maxNDVI (top) and sInt (bottom) for period 2001–2014 [based on eMODIS]. Non-significant trends (at $\alpha = 0.95$) are masked out

Appendix 6 – Significant trends of seasonal parameters

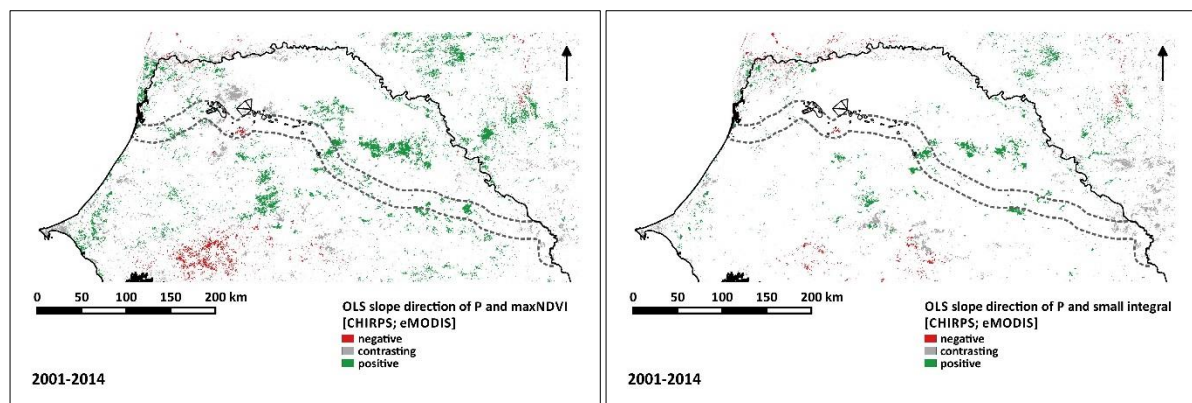


Figure A6. Overlay of OLS slope direction of precipitation and maxNDVI (left) and small integral (right), respectively. Areas with no significant maxNDVI trend (at $\alpha = 0.95$) are masked out [based on eMODIS and CHIRPS]

Appendix 7 – VHR images for projects before and after interventions

Projects ID1, ID2, ID3



Figure A7. VHR image from 18/01/2003 showing project ID1, ID2, ID3 (Map data: Google, DigitalGlobe)



Figure A8. VHR images from and 16/11/2011 (top) and 13/10/2003 (bottom) showing project ID1, ID2, ID3 (Map data: Google, DigitalGlobe)

Project ID15

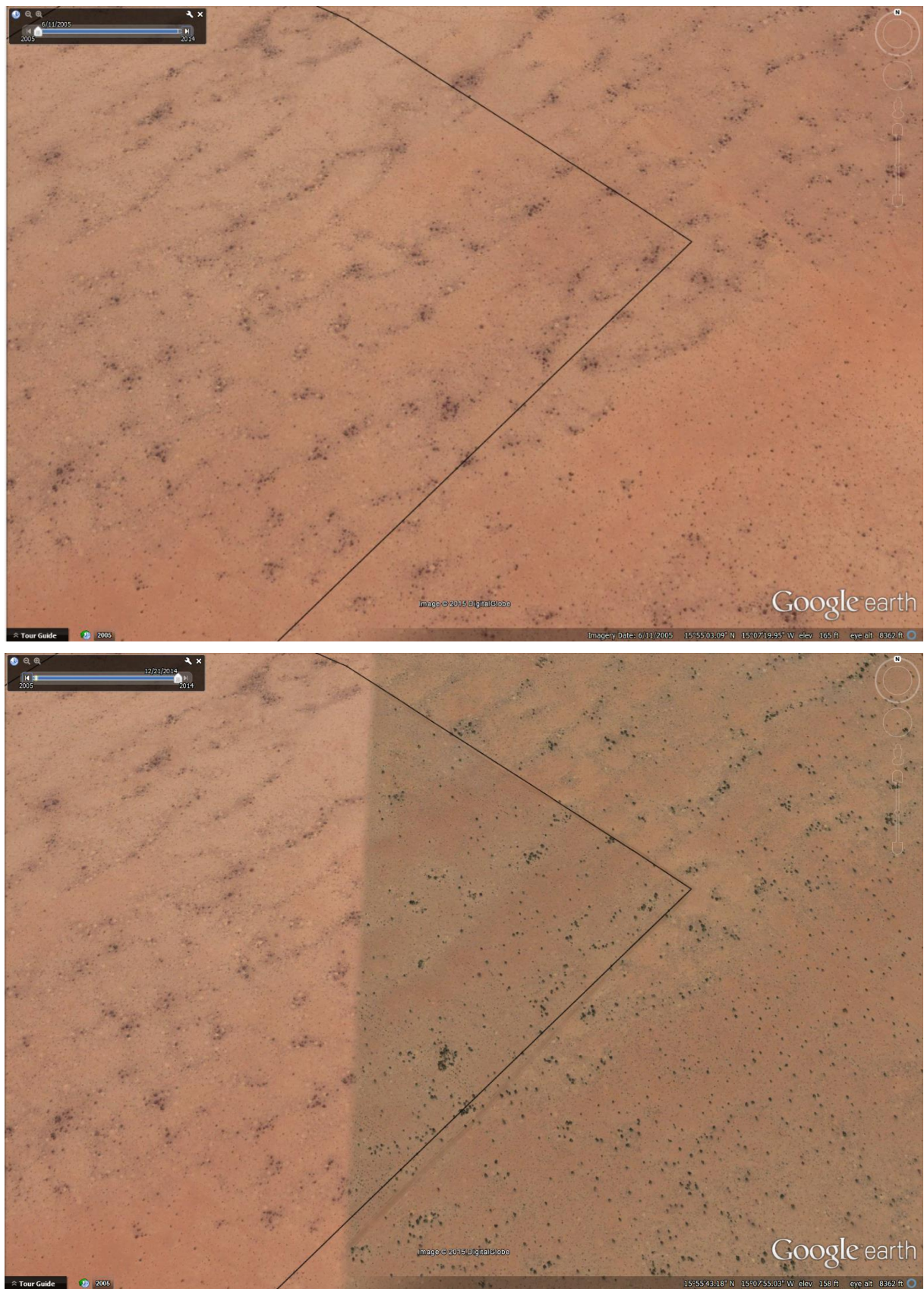


Figure A9. VHR images from 11/06/2005 (top) and 21/12/2014 (just right part; bottom) showing project ID15 (Map data: Google, DigitalGlobe)

Project ID16



Figure A10. VHR images from 11/06/2005 (top) and 21/12/2014 (just right part; bottom) showing project ID16 (Map data: Google, DigitalGlobe)

Project ID18

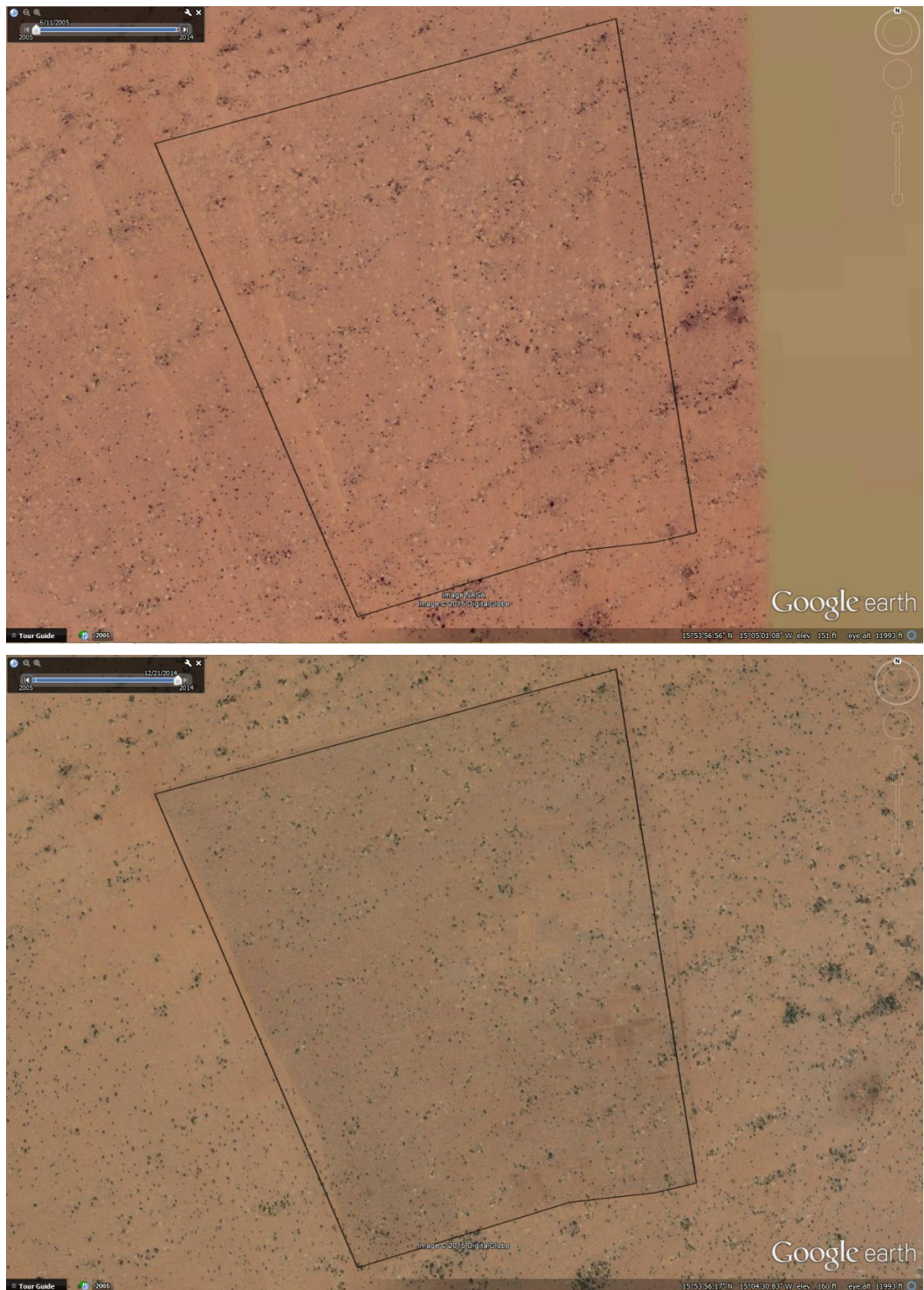


Figure A11. VHR images from 11/06/2005 (top) and 21/12/2014 (bottom) showing project ID18 (Map data: Google, DigitalGlobe)

Project ID20

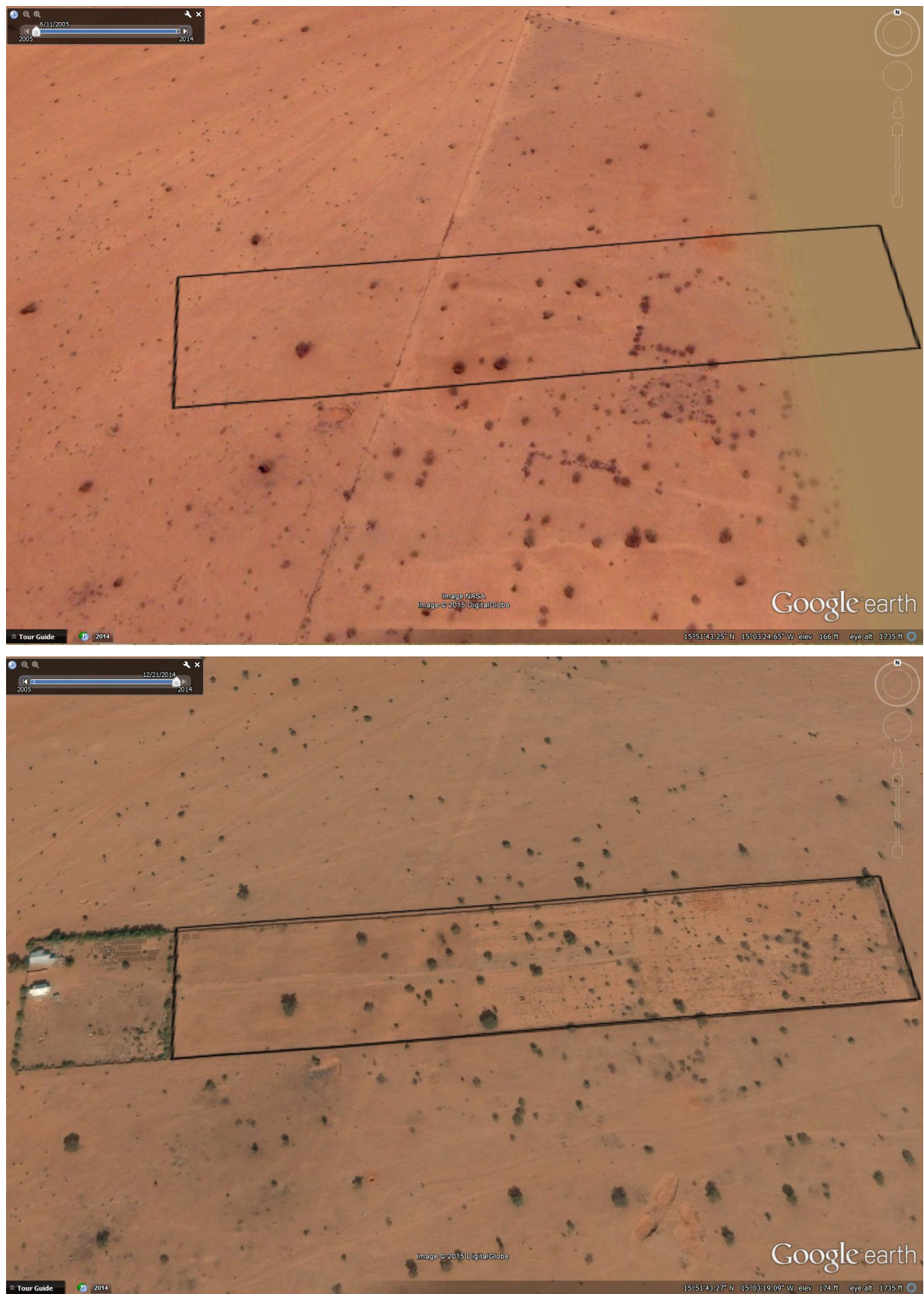


Figure A12. VHR images from 11/06/2005 (top) and 21/12/2014 (bottom) showing project ID20 (Map data: Google, DigitalGlobe)

Project ID22

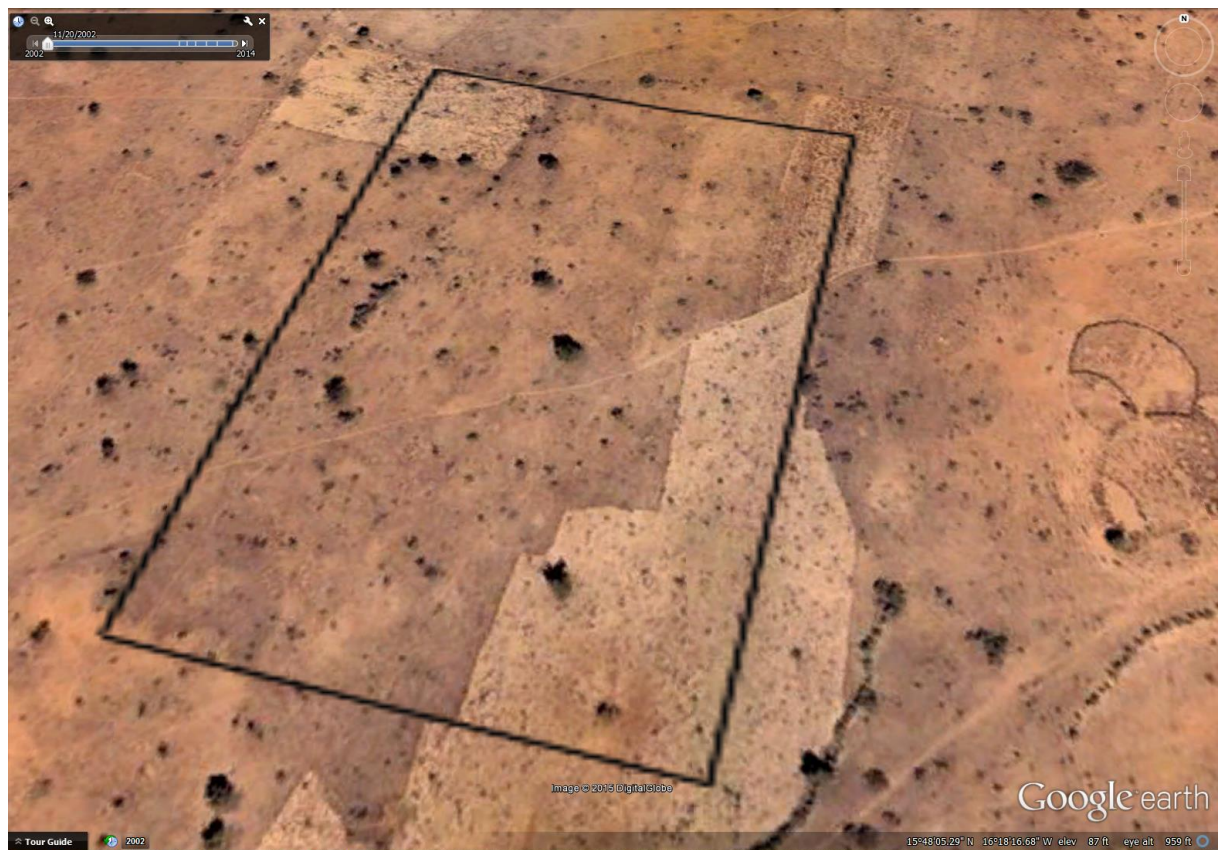


Figure A13. VHR images from 20/11/2002 (top) and 19/05/2011 (bottom) showing project ID22 (Map data: Google, DigitalGlobe)



Figure A14. VHR images from 13/11/2011 (top) and 08/02/2013 (bottom) showing project ID22 (Map data: Google, DigitalGlobe)



Figure A15. VHR image from 12/10/2014 showing project ID22 (Map data: Google, DigitalGlobe)

Project ID29



Figure A16. VHR images from 13/01/2003 (top) and 24/12/2010 (bottom) showing project ID29 (Map data: Google, DigitalGlobe)



Figure A17. VHR images from 26/12/2012 (top) and 08/02/2013 (bottom) showing project ID29 (Map data: Google, DigitalGlobe)

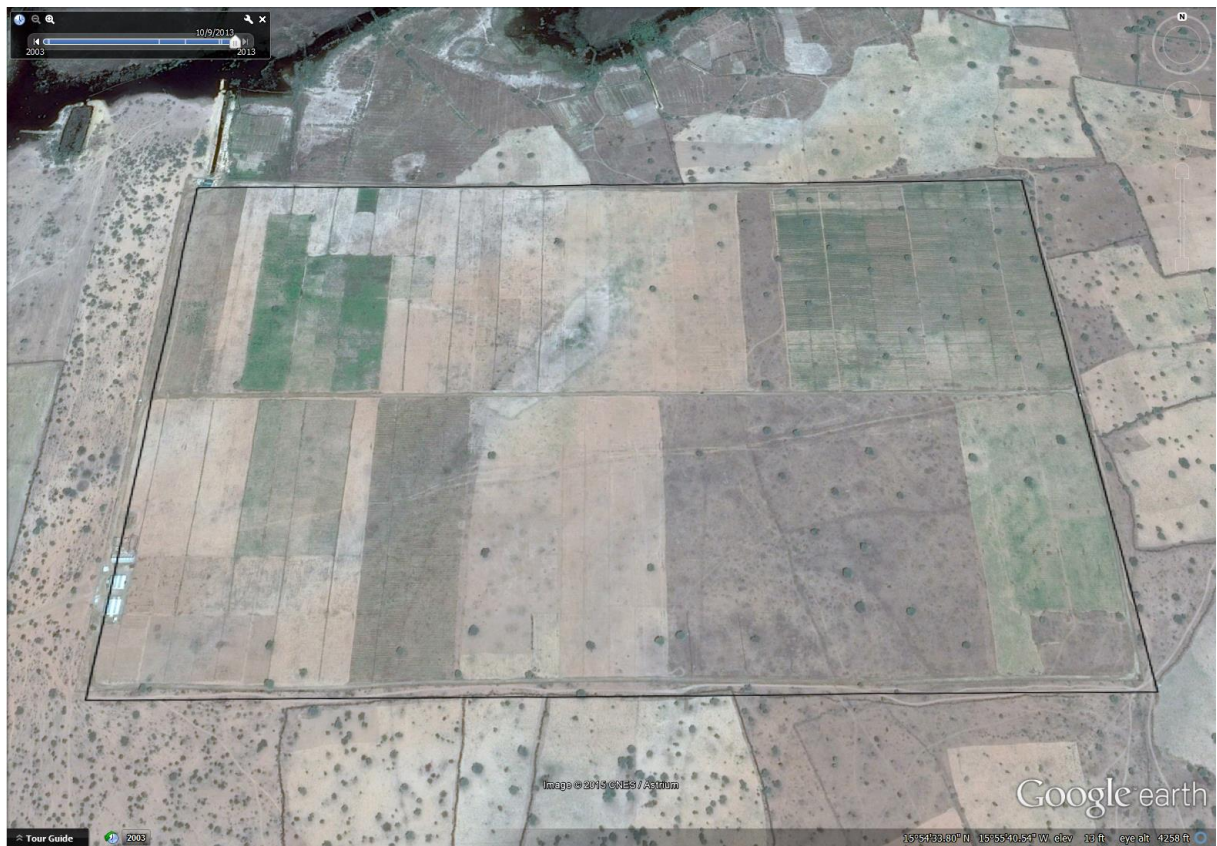


Figure A18. VHR image from 09/10/2013 showing project ID29 (Map data: Google, DigitalGlobe)

Project ID36



Figure A19. VHR images from 15/05/2006 (top) and 14/06/2013 (bottom) showing project ID36 (Map data: Google, NASA and DigitalGlobe)

Project ID37

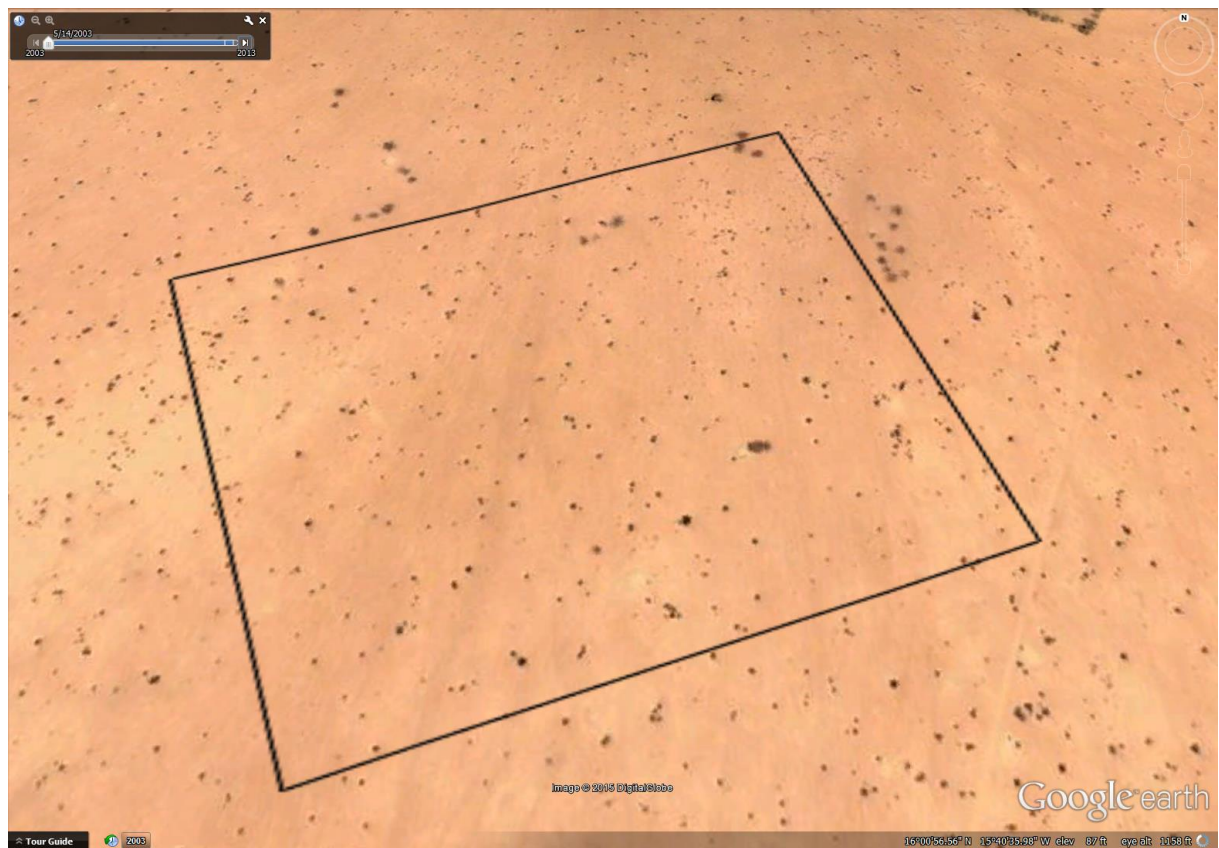


Figure A20. VHR images from 14/05/2003 (top) and 26/12/2012 (bottom) showing project ID37 (Map data: Google, DigitalGlobe)



Figure A21. VHR image from 14/06/2013 (top) showing project ID37 (Map data: Google, DigitalGlobe)

Project ID38

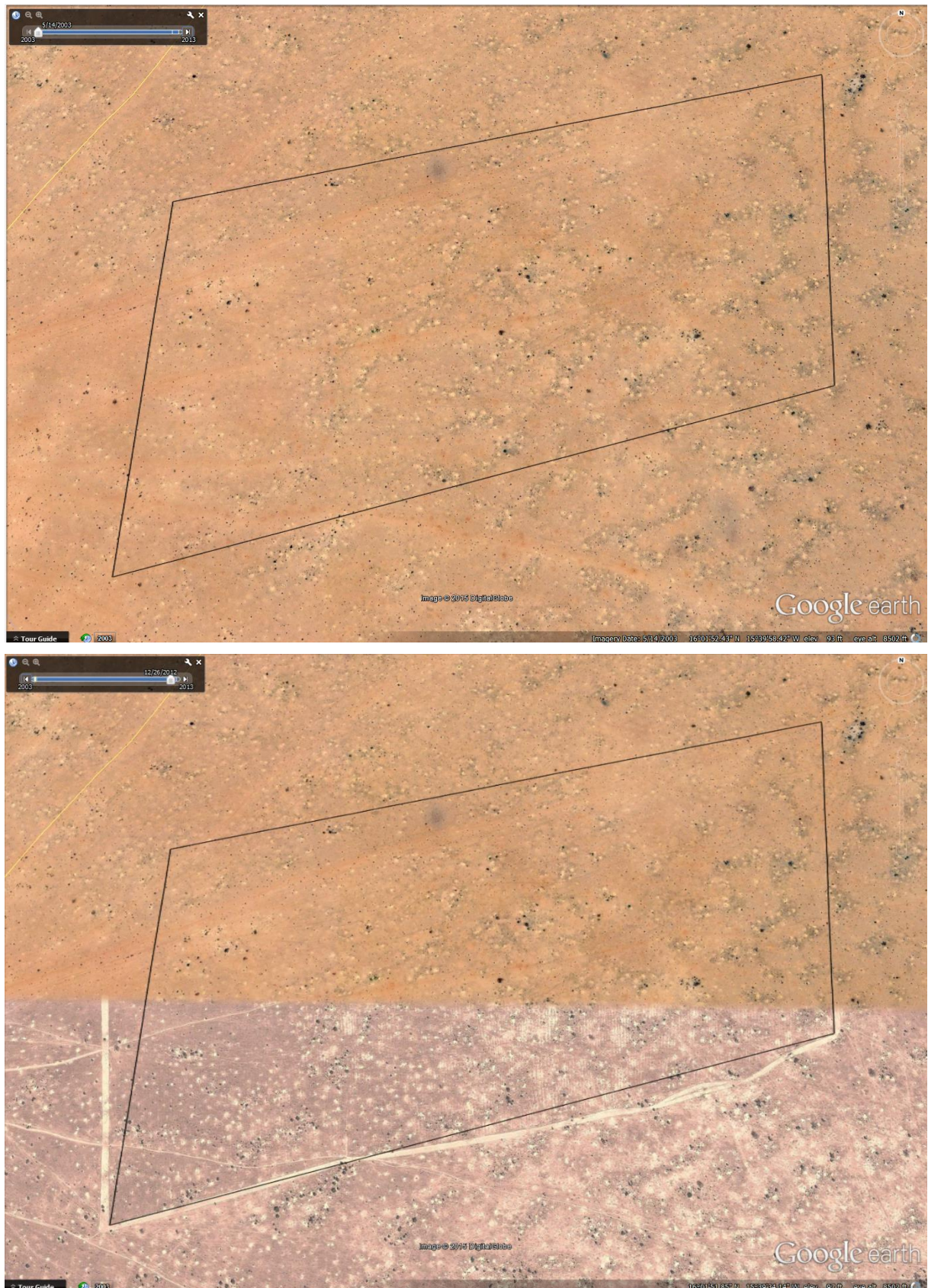


Figure A22. VHR images from 14/05/2003 (top) and 26/12/2012 (just lower part; bottom) showing project ID38 (Map data: Google, DigitalGlobe)

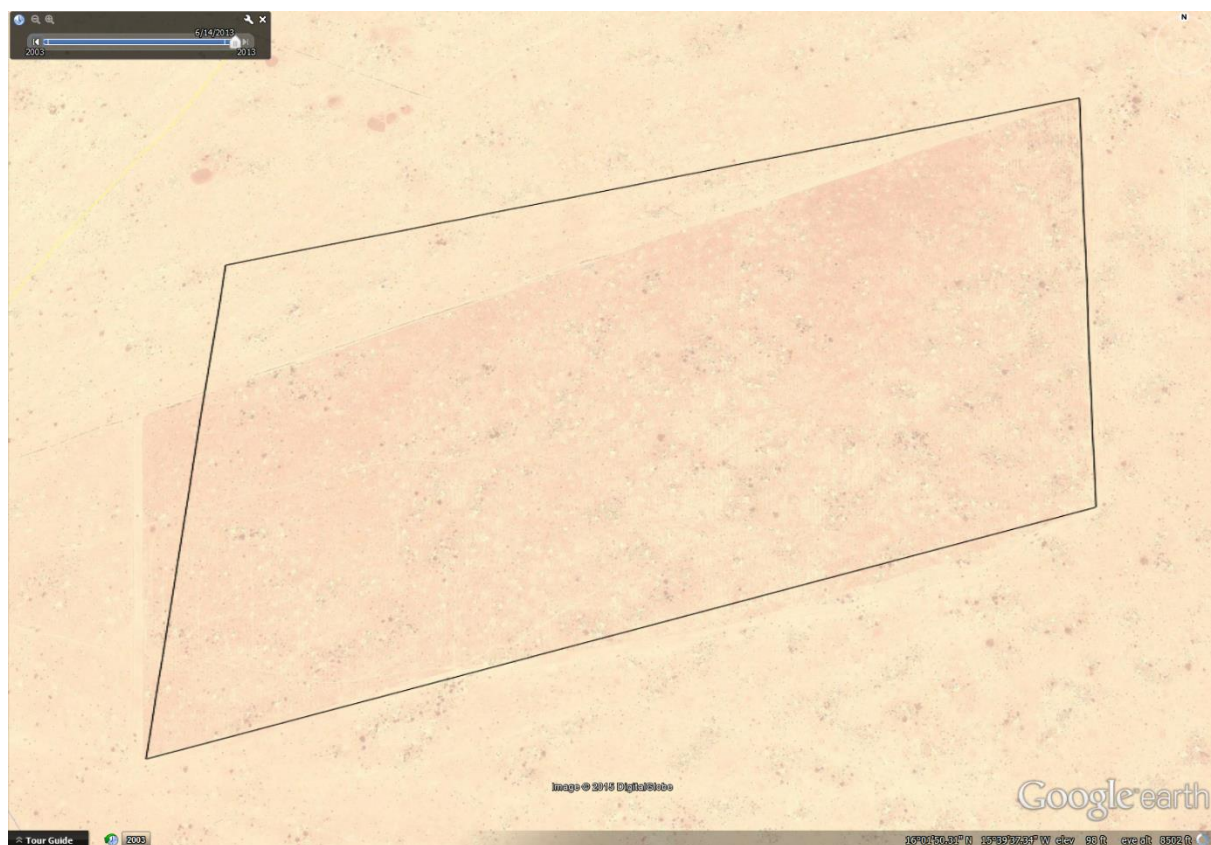


Figure A23. VHR image from 14/06/2013 showing project ID38 (Map data: Google, DigitalGlobe)

Project ID60

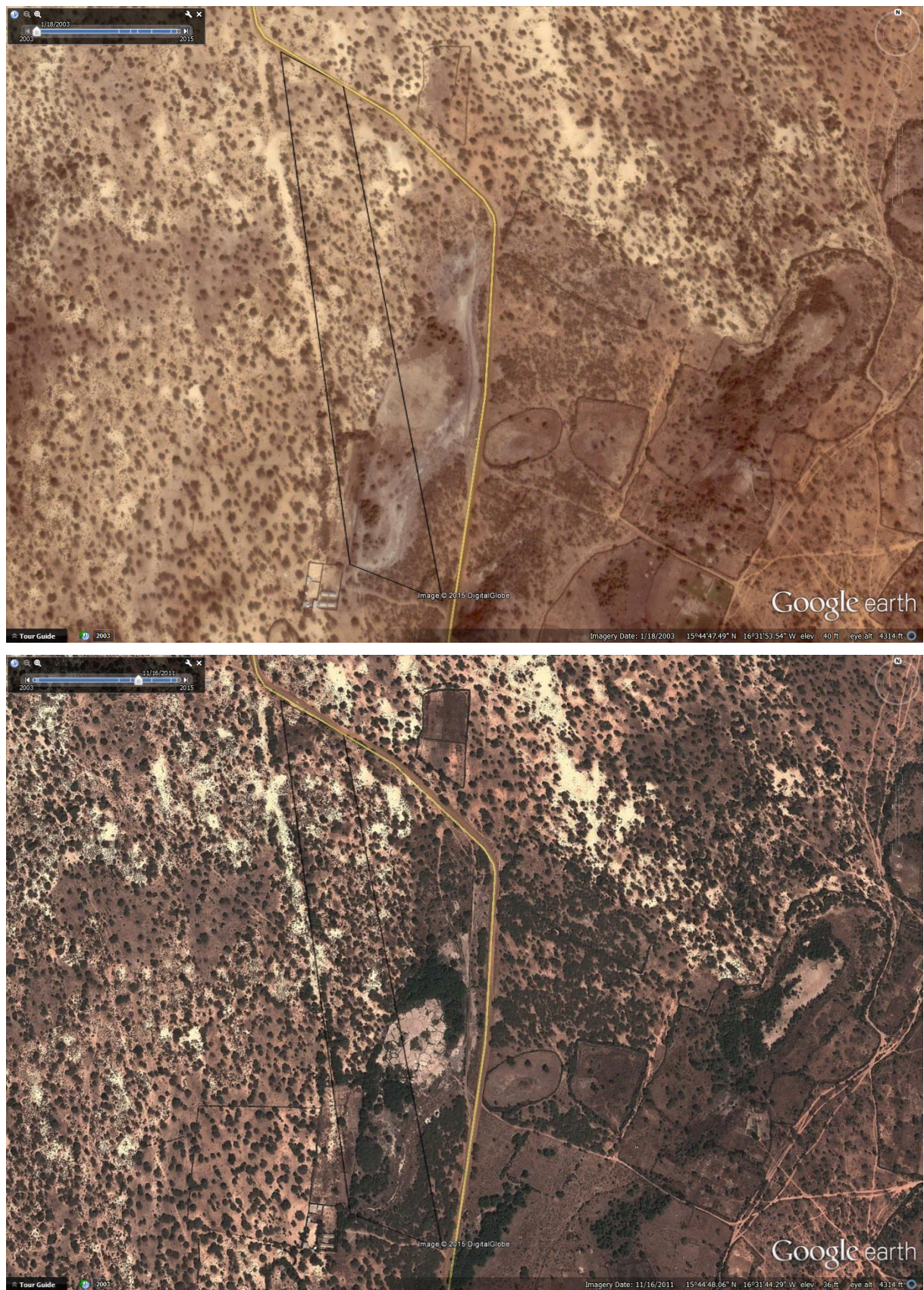


Figure A24. VHR images from 18/01/2003 (top) and 16/11/2011 (bottom) showing project ID60 (Map data: Google, DigitalGlobe)

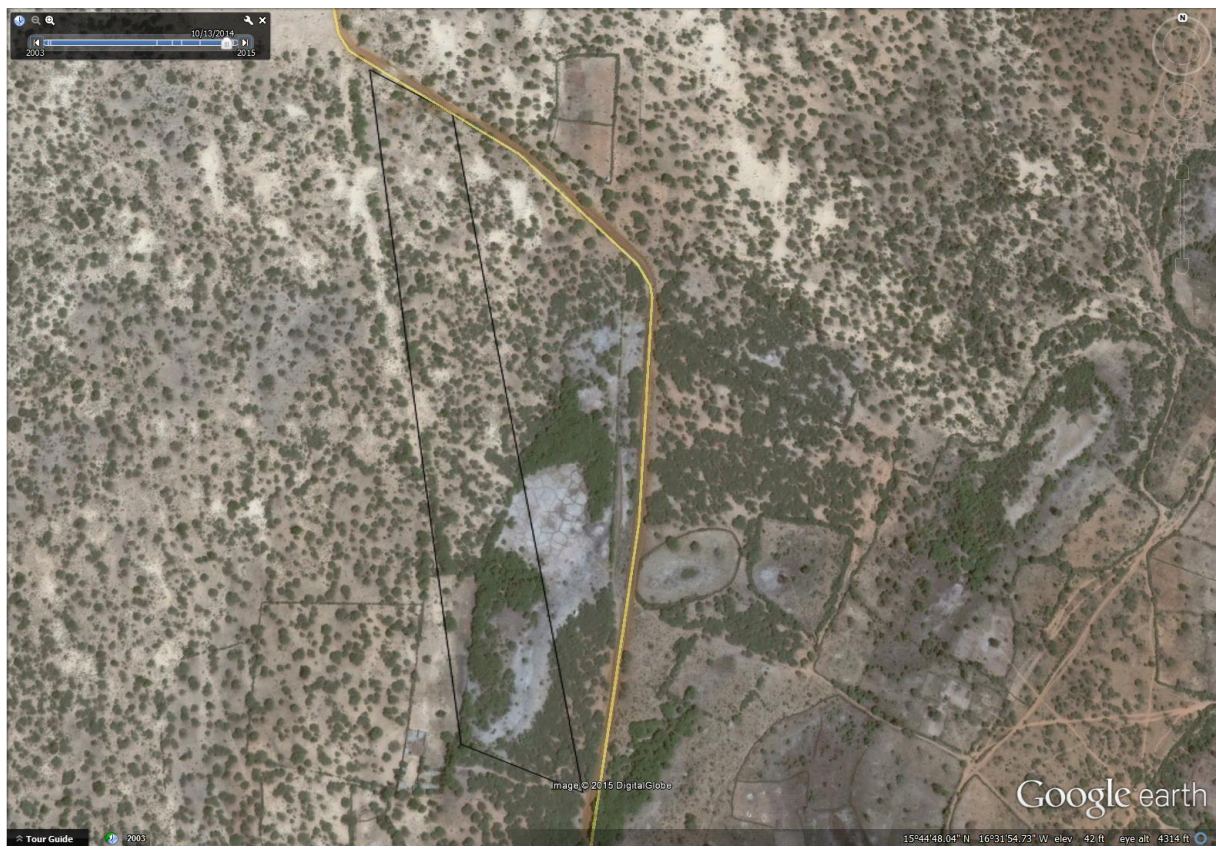
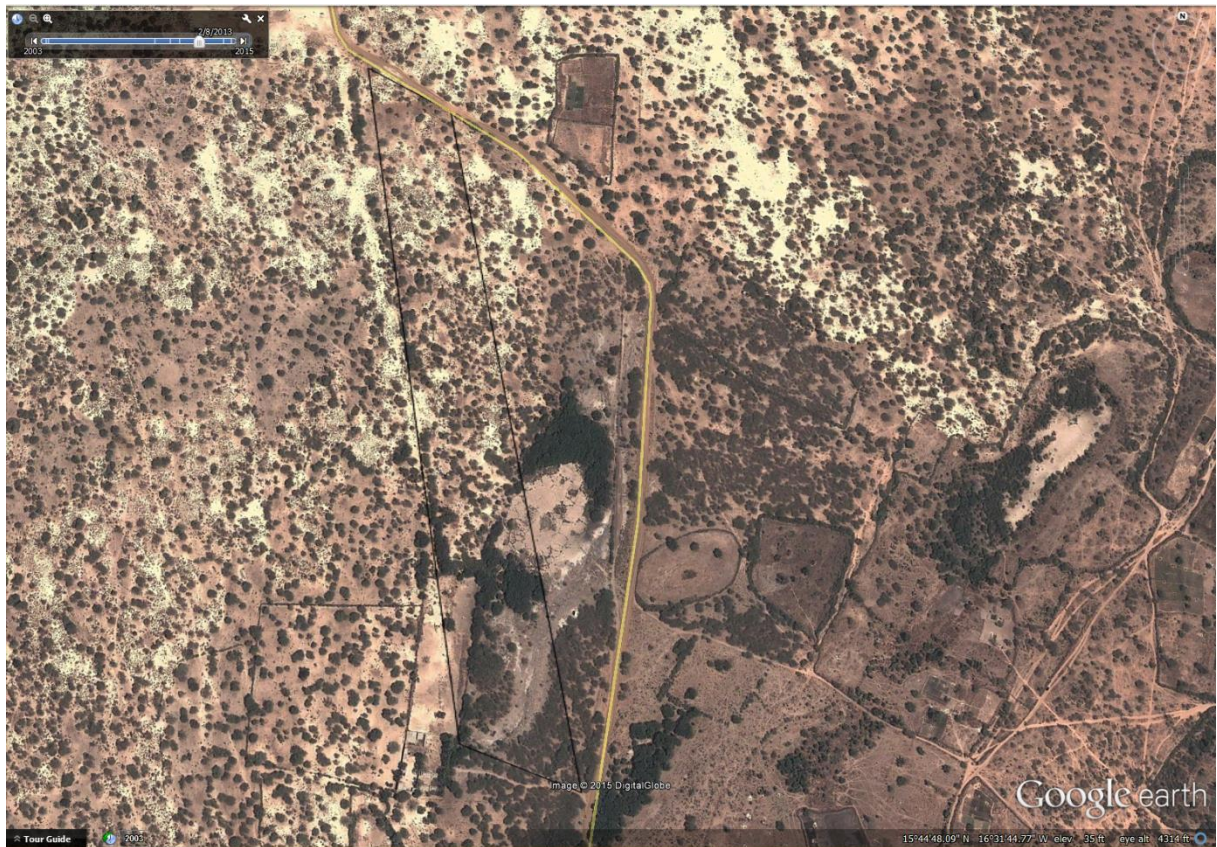


Figure A25. VHR image from 08/02/2013 (top) and 13/10/2014 (bottom) showing project ID60 (Map data: Google, DigitalGlobe)

Project ID61



Figure A26. VHR images from 13/03/2003 (top) and 16/11/2011 (bottom) showing project ID61 (Map data: Google, DigitalGlobe)

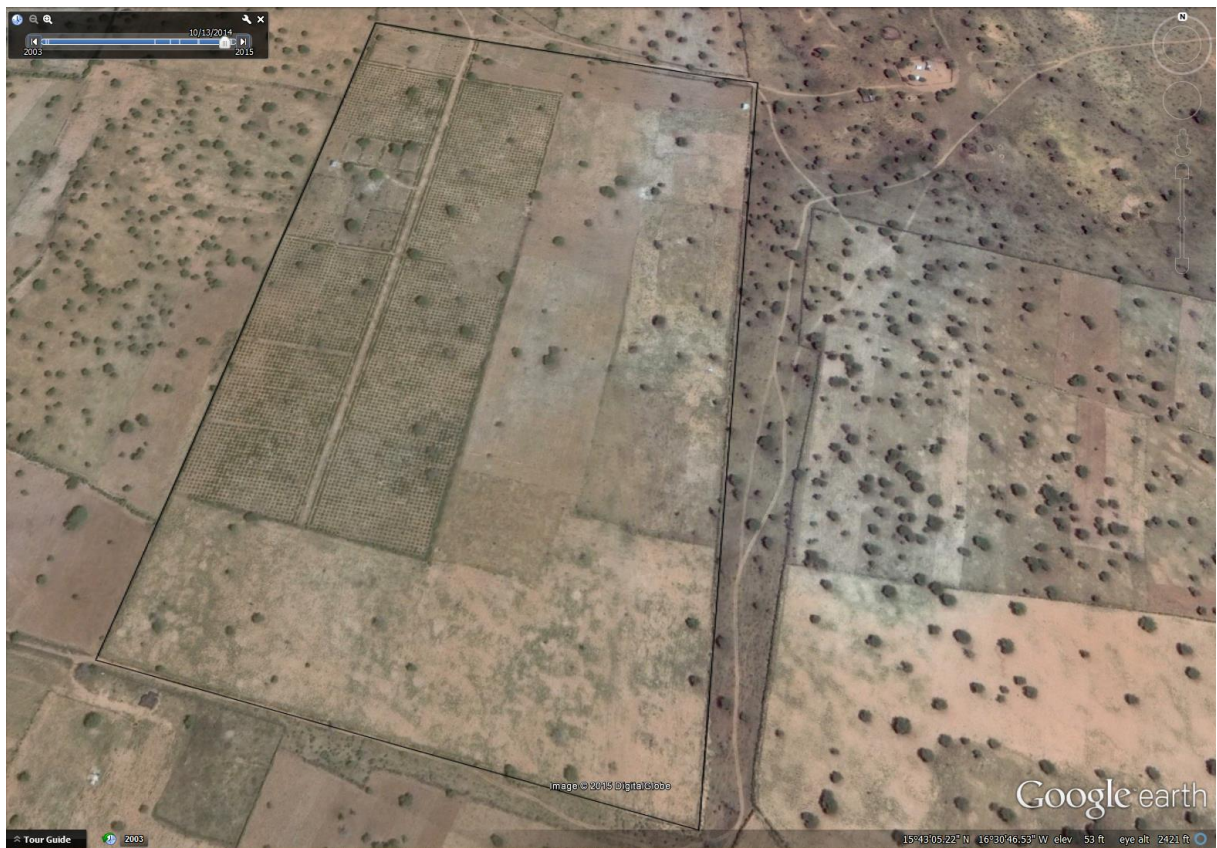


Figure A27. VHR images from 08/02/2013 (top) and 13/10/2014 (bottom) showing project ID61 (Map data: Google, DigitalGlobe)

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